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Rubbers, Natural and Synthetic

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ABSTRACT

The meaning of the word rubber has changed since the advent of synthetic materials similar to the natural product. It is now used to designate a class of flexible, elastic materials rather than a particular hydrocarbon product of natural origin. The synthetics are classified into five types. The mechanical properties of all types are determined not by the kind of chemical elements composing them but rather by the arrangement of these elements, the size of the molecules and by structures produced by vulcanization. All rubbers are modified by addition of other materials to fit them for a variety of uses. Differences in chemical composition and in the properties of natural and synthetic rubbers are shown in tabular form.

Mechanically, natural rubber is not surpassed by any synthetic rubber. However, in resistance to swelling by organic liquids, such as gasoline and oils, and to deterioration by sunlight or oxidizing agents synthetic rubbers have been found superior. These characteristics directed commercial applications to those fields where these properties are particularly needed.

Comparison of values of the various rubbers is constantly being made by technologists in the rubber industry. Therefore, when acceptance tests to insure suitability of products for particular uses are specified, it is advantageous to permit these men to select the materials which will best meet the requirements.

ALTHOUGH AT THE time preparation of this paper was first contemplated, considerable information had been published concerning the composition and properties of certain synthetic rubber-like materials, no article had appeared summarizing the work in this field and comparing the properties of the various kinds of synthetics. The Bureau of Standards, U.S. Department of Commerce, has since issued its Circular C427 entitled *Synthetic Rubbers, A Review of Their Compositions, Properties and Uses* by Lawrence A. Wood. This excellent summary is worthy of study by anyone interested in the potential uses of any of these materials. Recent as this publication is, it is nevertheless already inadequate to supply data concerning synthetics which have been announced within the past few months. There is no information in the circular about Ameripol rubbers* (The B. F. Goodrich Co.), Butyl rubber† (Standard Oil Development Co.) nor Chemigum (The Goodyear Tire & Rubber Co.). Furthermore, new varieties of Neoprene and Thiokol have been recently developed. The relative values of these newer synthetics for commercial applications have yet to be ascertained.

Presented at the Organic and Synthetic Materials session, Ninth Annual Meeting, I.Ae.S., New York, January 30, 1941.

WHAT ARE RUBBERS?

Rubber technologists are not unanimous in agreement as to what properties a synthetic material must possess to qualify as a rubber. Many synthetic substances, such as synthetic indigo or synthetic methanol, are chemically identical to those of the same name derived from vegetable origins. In contrast, all of the commercially available synthetic materials classified in this discussion as rubbers are distinctly different in composition from that of the natural product. Such valuable properties as strength, stretchiness and elasticity are not determined by the kind of chemical elements of which the rubbers are composed but rather by the arrangement of the atoms in the molecules, by the size of the molecules and by the structures produced as the result of vulcanization processes. Here the classification is based solely on physical properties and all these synthetics resemble natural rubber in some of the physical characteristics on which its wide usefulness depends. The meaning of the word rubber has changed. It no longer signifies a particular hydrocarbon material but has been widely adopted to characterize a class of substances similar physically to natural rubber regardless of their chemical composition. In order to qualify as a rubber a material should stretch readily to a considerable degree and, after release, retract forcefully and quickly; but no specific criteria have been generally accepted limiting the values for these properties.

* To be marketed as HYCAR rubber by the Hydrocarbon Chemical and Rubber Company.

† Industrial & Engineering Chemistry, Vol. 32, pages 1283–1292, 1940.

Varieties of Synthetic Rubber

In his circular Mr. Wood lists twenty-nine products under the heading *Varieties of Synthetic Rubber*. Some of these, notably Methyl Rubber made in Germany during the World War of 1914–18, are not now obtainable commercially. The list also includes essentially identical products under different names. The synthetics which recently have been or are now of commercial interest in this country are of five types:

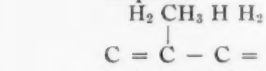
(1) Polymers of chloroprene	Neoprenes
(2) Reaction products of aliphatic dihalides with alkali polysulfides	Thiokols
(3) Co-polymers of butadiene with other polymerizable compounds	Perbunan Buna S Ameripols Hycars Chemigum*
(4) Plasticized polymers of vinyl chloride	Koroseal
(5) Polymers of isobutylene	Vistanex

All Rubbers Consist of Long Molecules

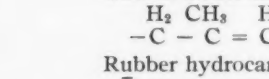
As has been stated, all of these differ chemically from natural rubber. It was postulated many years ago that the molecules of natural rubber are made up of a great number of C_5H_8 groups derivable from isoprene by a shift of chemical linkages. The first table shows the structure of isoprene and of the hydrocarbon of natural rubber.

Table 1

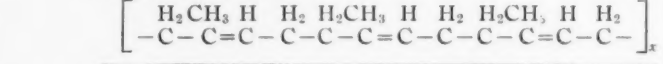
Isoprene



Unit of which the rubber hydrocarbon is constructed



Rubber hydrocarbon



Calculations indicate that rubber contains from 200 to 4400 C_5H_8 units per molecule varying with preliminary treatment of the hydrocarbon and the method of measuring its molecular weight. How the long chains of carbon atoms are built up by growing plants is not definitely known; but similar chains of carbon atoms or atoms of carbon interspersed with other elements can be produced by artificial means through polymerization of relatively simple molecules. Chemical polymerization may be likened to the formation of a metal chain, the individual links representing the simple molecules, the completed chain the polymer. The links may be all alike or links of different materials may be joined in the same chain. Natural rubber may be considered as a polymer of isoprene of high, though not uniform, molecular weight. It should be noted, however, that no polymer of isoprene yet made artificially has approached the quality of rubber closely enough to be suitable for practical use. Similarly the molecules of synthetic rubbers are chain polymers of great length. It has been ascertained that the size of the polymers, *i.e.*, the length of the chains, and the degree of cross-linkage between them which occurs to some extent during polymerization determine the physical properties of the materials. These factors are controlled by regulation of temperatures and by the kind and amount of catalysts used in the polymerization process. Such attributes as resistance to swelling by solvents and electrical properties are largely dependent on the chemical composition but strength, stretchiness and elasticity are determined primarily by structure.

* India Rubber World, Vol. 103, No. 1, page 44, 1940.

Changes Produced by Vulcanization

In its unvulcanized state natural rubber is more or less plastic and when suitably prepared can be readily sheeted, extruded in tubular or other shapes, squeezed into the meshes of textile fabrics or spread in solution on their surfaces. These properties, important for the fabrication of articles, are possessed in varying degrees by all the synthetic materials here classified as rubbers. Vulcanization changes natural rubber from a plastic substance, soluble in hydrocarbon solvents and susceptible to marked physical and chemical alteration within the range of ordinary weather temperatures, to a new material highly elastic, insoluble (though swollen) in hydrocarbon solvents and relatively insensitive to change over a considerable temperature range. Similar changes may be induced by vulcanization in most of the synthetic rubbers.

Mechanism of Vulcanization

Synthetic rubbers with the exception of polymers of vinylchloride and of isobutylene contain doubly bonded atoms. Vulcanization usually involves breakage of one bond at some of these points and either direct chemical union with a similar bond of an adjacent chain (as in the case of Neoprene) or union indirectly through a vulcanizing agent such as sulfur (as with rubber, the Bunas, Ameripols and Butyl rubbers). It is obvious why the polymers of vinyl chloride and isobutylene, which contain no double bonds, will not vulcanize in this manner. Within certain temperature limits, however, these unvulcanized synthetics manifest some of the important properties of vulcanized rubber and may logically be included in the rubber category. In soft rubber compositions cross-bonding during vulcanization occurs at relatively few points. By incorporation of large proportions of sulfur with natural rubber and vulcanizing at high temperatures for relatively long periods

all of the double bonds may be reacted and hard rubber (ebonite) produced. The Bunas and Ameripols are like natural rubber in this respect but neither Neoprene nor Thiokol vulcanizes to the hard rubber state. Hard rubbers of Perbunan or Ameripol are superior to that made from natural rubber in resisting flow under load at high temperatures.

New Synthetics Expected

Investigations of the co-polymer field, though intensively pursued for some years past, have by no means covered all possible combinations. It is reasonable to expect that continued research may within a few years disclose several new synthetic rubbers made from as yet untried combinations, each possessing some desirable characteristic to a degree as yet unobtained. If this expectation is realized the usefulness of rubber-like materials, already extended by synthetics, will spread far beyond the limits imposed by the properties of materials now available.

The Properties of All Rubbers May Be Modified

The number of uses of natural rubber unblended with other materials is decidedly limited. For one hundred years the rubber industry has been seeking improved methods of modifying rubber in order to make it more resistant to abrasive wear, oil, heat or other deteriorating materials or forces affecting serviceability. It has been necessary to produce compositions of different colors and of various degrees of hardness or rigidity—in fact, to modify all the properties exhibited by vulcanizates containing only rubber and sulfur. Such alterations are achieved by mixing with rubber before vulcanization selected kinds and amounts of other materials. These compounding ingredients are of great variety—finely divided pigments, softeners such as oils or tars, fibrous materials, vulcanization accelerators or age resisters. During this period in designing their products manufacturers of rubber goods have learned also various ways of combining the advantages of rubber compositions with desirable properties of other materials such as wood, metals or textile fabrics. Like expedients are now being followed in modifying synthetic rubbers and designing articles in which they are used. Some of the modifying materials used with natural rubber produce similar effects with synthetics, but it has been found that better results are sometimes obtained from materials not formerly adopted for rubber compounding. Just as study and experiment have disclosed ways of improving in certain respects the properties of natural rubber, it is to be expected similar improvements will be made in compounding technique with synthetics.

Serviceability of Rubbers Constantly Improved

To meet the many requirements imposed by a wide diversity of uses hundreds of rubber compositions have been developed. For a specific service those are selected whose properties are best suited to meet the requirements. Compositions are frequently improved but, no matter how great the improvement, demands for products to withstand more severe conditions never cease. Conveyor belts, for example, originally required to carry small aggregates at ordinary temperatures, must now withstand the shock of large masses dropped upon them and, at times, must transport materials at temperatures only slightly below red heat. Belts capable of withstanding this severe punishment are now available. Such developments require the invention not only of new rubber compositions but of improved fabrics and necessitate new designs for many articles. The improvement of pneumatic tires and inner tubes is an excellent example of this response to demands for better quality and extension of the field of application. The increased wear of treads on passenger cars from 3000 miles at slow speeds to 15,000 miles and more at the high speeds of modern cars (improvement in tread wear resistance during the past ten years has averaged 10 per cent a year), the design of tires capable of resisting temperatures of 220°F. generated in high speed bus service, the construction of tires each capable of carrying 20 tons for heavy haulage, the improvement of inner tubes so that they no longer tear to pieces when a tire is run flat after sudden deflation until the car is stopped—all these illustrate the sort of progress made in the compounding of rubber and the design of products. The rubber industry has not been static and there is no indication that the limit of improvement will soon be reached.

Rubber Articles Are Assembled before They Are Vulcanized

Rubber differs from many materials in that, with few exceptions, vulcanized rubber is not sold in sheets, tubes or other standard forms to be cut to size or shape to serve as unit parts for fabrication of structures, machines or apparatus. A transmission belt, for example, is not made by plying together sheets of vulcanized rubber and lengths of cotton duck and cementing the various parts together nor are vibration dampeners made by cementing or riveting a block of rubber between appropriately shaped steel plates. The various parts of rubber articles are assembled before the rubber is vulcanized and these are welded together during the vulcanization process which develops the desirable properties of the rubber portions.

Rubber Compositions Are of Great Variety

Inasmuch as all rubbers are greatly modified by compounding and their compositions are usually combined with other structural materials to render the rubbers useful for a great variety of services, it is evident that no table of properties can be compiled representative of

TABLE 2

E = Excellent, G = Good, F = Fair and P = Poor

Property	Rubber	Neoprene	Thiokol	Koroseal	Perbunan	Oil Resistant Ameripol
Abrasion and tear resistance	E	G	P	E, if heat is not generated	E	E
Adhesion to metals	E	E	F	F	E	E
Aging in storage	E	E	E	E	E	E
Chemical resistance:						
Oxidizing solutions	P	P	P	E	P	P
Ozone	P	E	E	E	F	F
Solutions of salts, alkalies and acids	G	G	G	G	G	G
Color range	E	G	P	E	F	G
Resistance to cutting	G	G	P	E	G	G
Resistance to diffusion of gases	F	G	E	E	G	G
Elasticity and rebound	E	G	P	F	G	F
Electrical properties:						
Conductivity	F	F	F	F	F	F
Resistance to corona cracking	P	E	E	E	P	P
Dielectric strength	E	F	F	E	F	F
Flame resistance	P	G	P	E	P	P
Resistance to flex-cracking	G	G	F	E	G	G
Resistance to flow:						
Cold	E	G	P	F	E	E
Hot	E	F	P	P	E	E
Hardness range–durometer A	20–100	10–90	20–80	10–100	10–100	10–100
Low heat generation through hysteresis	E	F	F	—	F	F
Freedom from odor	G	F	P	E	F	F
Resistance to swelling in						
Chlorinated or aromatic solvents	P	P	G	Shrinks because of extraction of plasticizer.	P	F
Lacquer solvents	P	P	G		P	F
Mineral oil or gasoline	P	G	E		G to E	E
Water	F	G	—	E	E	E
Resistance to deterioration by mineral oil	P	E	F	G	E	E
Specific gravity of basic material	0.93	1.25	1.35	Av. plasticizer content 1.30	0.98	1.00
Range of stretchability	E	G	F	F	G	G
Resistance to checking in sunlight	F	E	E	E	F	G
Stability of properties with change of temperature:						
Cold	E	F	E	F	G	G
Heat	G	E	P	P	E	E

any vulcanized rubber as a specific material. Values for load deflection relations, tensile strength and elongation at rupture, flow (hot or cold), specific gravity, thermal or electrical conductivity, thermal expansion, hardness and so on vary with each change of composition and sometimes with the degree of vulcanization. In comparing the properties of compositions of several rubbers each of which may be varied so widely one cannot be very specific. Certain general comparisons may be made, however, which will be of value to those who are interested in applications of rubbers for specific uses. Table 2 tabulates the relative merits of rubber and the synthetics which have been used commercially in this country. Vistanex is omitted because its applications as a substitute for natural rubber are not important, although it is used in mixtures with natural rubber and for electrical insulation to some extent.

Special Values of Different Rubbers

The mechanical properties of compositions of natural rubber are not surpassed to any marked extent by those of synthetic rubber stocks. For this reason, unless their cost can be reduced sufficiently to be competitive, it is probable that synthetic rubber will not replace the natural product in articles which depend for utility on such properties alone. It frequently happens, however, that in service, rubber must be subjected to influences which rapidly impair its mechanical excellence. Contact with oil may be unavoidable or exposure to bright sunlight or to high temperature. In such cases compositions of synthetics or of mixtures of synthetics with natural rubber must be used. Occasionally some one material so far surpasses all others that it alone may be used successfully. For example, no synthetic has yet been found to equal natural rubber in resiliency or extensibility. Golf balls, made by winding rubber thread under tension, and stationers' bands are markedly superior to similar products made of synthetic materials. Also, linings for metal tanks to resist the action of nitric-hydrofluoric acid mixtures used for pickling stainless

steel or of chromic acid plating solutions are made of Koroseal because of the outstanding superiority of this material in resisting these powerful oxidizing solutions. For tubes of hose to conduct lacquer solvents and thinners Thiokol is the most resistant of any of the synthetics which have yet appeared.

Oil Resistance and Its Practical Applications

The predominant virtue of synthetics over natural rubber is their resistance to oil and organic solvents. This fact has directed their first use to those types of service where the flexibility of rubber was needed but, because of the action of such liquids, compositions of natural rubber could not be satisfactorily applied. A few of these may be mentioned by way of illustration. The superiority of rubber inking rollers on newsprint presses over the older glue-glycerine compositions indicated their possible extension to other types of printing. It was found, however, that rubber which withstood the action of newsprint inks containing no drying oils was entirely unsuited for use with inks composed of these oils containing manganese or cobalt driers. Rollers of synthetic rubbers, however, not only resist the action of oils and driers but do not soften when heated as the glue-glycerine rollers do. This has led to their adoption for a new printing process in which the ink, a solid at room temperatures, must be melted by heated rollers on the press. This is the process used in printing the new paper, PM.

Water-lubricated rubber bearings are commonly used for the outboard bearings of propeller shafts on vessels plying in silt-bearing waters. The rubber is deformed by any particles of sand which enter between it and the metal shaft and these particles travel along the shaft and are expelled without scoring the metal. In exceedingly muddy water such as is produced by the cutter heads of dredges rubber bearings have yielded extraordinarily long service. When, however, bearings of this sort were used on vessels at Maracaibo, Venezuela, where the surface of the water was covered with a film of oil from neighboring wells, the rubber swelled and softened and the bearings soon failed. Substitution in the bearings of synthetic rubber compounds which are not swollen or deteriorated by oil overcame the difficulty.

Because of their resistance to swelling in gasoline, synthetics are replacing natural rubber in hose for dispensing this fuel. Here a change in the construction of the hose has been made. The older type in which a layer of rubber was sandwiched between an inner flexible metal tube and an outer jacket of tightly woven cotton strands is being displaced by hose of conventional design in which the tube is made of a synthetic rubber composition. Similar superiority against the action of lubricating oils led to adoption of synthetics for hydraulic brake hose for use with fluids containing mineral oil, though natural rubber has proved adequate for use with fluids of the glycerol type.

It should be noted that different grades of gasoline and lubricating oils affect synthetics differently. Gasolines containing benzol, for example, are more severe in their action than aliphatic hydrocarbons alone. Nor are all lubricating oils designated by the same S.A.E. number alike in their action.* Furthermore, the degree of swelling is not always indicative of the value of a compound. Some which swell but slightly become weak and inextensible in contact with oils.

Resistance to Sunlight

Another superiority of certain synthetics lies in their resistance to checking in sunlight. This fact led to the adoption of Neoprene in a surface coating for rubber airplane de-icers exposed at times to bright sunlight which induced checking and cracking. Because the higher specific gravity of Neoprene would increase the weight and because it stiffens at higher temperature it was undesirable to replace rubber entirely throughout the structure. It is interesting, too, that by compounding the Neoprene with graphite, sufficient conductivity was obtained to prevent the potential of static charges built up during flight from becoming sufficiently high to cause discharge through the de-icer structure, which had often occurred before Neoprene coatings were adopted. The electrical conductivity and resistance to gasoline of compounds of synthetic rubbers has made practical their use as hose nozzles at filling stations where the flexibility and softness of rubber have long been recognized advantages over metal for this purpose.

Two other respects in which synthetics surpass natural rubber are their resistance to swelling by water, especially under heat and pressure, and their greater resistance to diffusion of gases.

Combined Characteristics Often Decide Choice of Materials

In many cases no one property determines the selection of a material for service. A combination of several properties must be secured and technologists who design the various compositions must select those materials which yield the best all-round characteristics for the purpose. Good resistance to abrasion is obtainable from most of the synthetics under certain conditions of service. Shoe soles of Koroseal will outwear rubber compounds of the same hardness; but if the service were such that the material became heated as the result of friction Koroseal would not be considered. If again, to the demand for good resistance to abrasive wear is added the requirement that the composition must withstand heating under rapidly repeated compressions natural rubber would be selected, but if oil resistance is a further requisite the technologist will abandon rubber entirely and, necessarily accepting some heat generation, pick one of the synthetics. Unfortunately, not

* Industrial & Engineering Chemistry, Vol. 32, pages 1069–1072, 1940.

all of the synthetics which exhibit excellent resistance to the action of oil possess satisfactory characteristics for use as electrical insulation. Of the oil resistant varieties Koroseal has found the widest use in the electrical industry as insulation or as oil-resistant sheathing on wire and cables. In these constructions, the fact that Koroseal does not require vulcanization is a decided advantage.

Specifications for Rubber Compounds

In order to be certain of obtaining articles suitable for their needs purchasers of rubber goods often specify certain features of construction or composition which they believe will insure the desired qualities. With this in view some have drawn specifications designating that the compound shall be made of a particular synthetic rubber. This practice is undesirable for at least two reasons. In the first place it prevents the manufacturer from utilizing any other material even though it may furnish to the consumer goods of better quality or lower cost or both. In fact, improvement of quality, especially of articles built up of various parts, may be largely dependent on the processing properties of the synthetics—a feature about which the consumer usually has no information. Second, it hinders the commercial development of new synthetics by reducing the amount which might otherwise be used. Costs of these materials are greatly influenced by the volume of production. If a new synthetic, no matter how good, will not be accepted, its use cannot increase as it might in a free market with competition based on quality alone. The practice of specifying acceptance tests of such character as to insure suitability for the desired purpose and leaving to the manufacturer the choice of the materials from which he can best secure the necessary properties must inevitably result in the purchaser's obtaining higher quality and better value for his expenditure. No chemical manufacturer who produces synthetic rubbers is unbiased in promoting sales of his product. Even though he knows that for certain purposes a competitive material is preferable, he does not recommend its use. Technologists in rubber manufacturing establishments, on the other hand, utilize all kinds of synthetics. They are interested only in obtaining the best materials available. They are constantly making comparisons among the commercial synthetics and adopting each for specific types of service on the basis of their merits. Their experience and judgment should be of value to engineers or inventors who need to apply rubber compositions for attaining certain objectives. Specifications should permit them to choose the materials best suited to each type of service.

Conclusion

The development of synthetic rubbers is a new and expanding field. Compositions of these synthetics offer no marked advantage over those of natural rubber in their mechanical properties but are far superior in resisting certain deteriorating influences often encountered in service. The earliest applications of synthetic rubbers were based on their outstanding resistance to sunlight, gasoline and oils. Occasionally some one material is satisfactory for a particular service. More often the desired results may be obtained from two or more of them. Superiority has been found in synthetics over natural rubber in:

(1) Resistance to swelling and deterioration in contact with oils, organic solvents and water.
(2) Resistance to cracking in sunlight.
(3) Resistance to deterioration by heat.
(4) Resistance to powerful oxidizing agents.
(5) Resistance to diffusion of gases.

Rubber still exhibits superiority to all the synthetics now available in:

(1) Elasticity and rebound
(2) Low-heat generation through hysteresis.
(3) Extensibility.
(4) Resistance to stiffening at low temperatures.

This is the picture today. How it will be changed within the next few years or even the next few months no one can safely predict.

The Daytime Photoelectric Measurement of Cloud Heights

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ABSTRACT

A photoelectric detector is used in conjunction with a modulated beam of light for the measurement by triangulation of the height of clouds during the daytime. An a.c. operated mercury-arc lamp is used to obtain the modulated beam. An electronic "synchronous switch" is used to eliminate the effect of the varying background brightness of the clouds. The shot noise of the phototube resulting from the relatively high brightness of clouds during the daytime limits the detection. Dark overcast clouds at an elevation of 9000 feet have been detected.

INTRODUCTION

A BEAM of light incident on the base of a cloud is scattered to such an extent that at night the spot produced by a searchlight is generally visible. This phenomenon of scattering of light by water drops has made possible the employment of optical methods for the measurement of cloud heights. Middleton has discussed the use of the ceiling projector[1] for night measurements,* at which time the angular elevation of the spot can be determined by means of a visual instrument such as an alidade. The height of the cloud is determined from the solution of the vertical triangle formed by the line of sight on the spot, the beam of the projector, and the base line connecting the projector and alidade.

Several years ago Middleton initiated the first work on a photoelectric detector which would extend the use of the ceiling projector to the daytime measurement of cloud heights through the utilization of a modulated beam. Meanwhile Messrs. F. V. Jones and A. H. Mears of the U.S. Weather Bureau had been considering the same solution of the problem when Middleton's work became known to them. The Weather Bureau requested the National Bureau of Standards to develop the necessary equipment for measuring cloud heights in this way. The present paper describes a projector equipped with a mercury-arc lamp operating on alternating current to obtain a modulated beam and a phototube and amplifier which have been used to detect daytime clouds up to 9000 feet.

Presented at the Instruments Session, Ninth Annual Meeting, I.Ae.S., New York, January 29, 1941.

The authors wish to express their thanks to Mr. E. A. Johnson of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, for several helpful discussions and for granting them the permission to read reference 3 in manuscript form.

* Middleton also calculated the amount of signal light which is reflected from the spot, and Section 3 of his paper applies equally well to daytime and nighttime measurements.

THE MEASURING EQUIPMENT

a. Theory

Modulating a projected beam so that, after scattering, the light retains its original "identification-tag" was suggested by Tuve[2] as a possible means of studying the upper atmosphere. This suggestion would seem to make it possible to use a phototube and tuned amplifier to sort out completely the identified light from the background light. But the shot noise of the phototube resulting from the background light and the other noises associated with the phototube and the amplifier limit the minimum modulated light signal that can be detected.[3, 4] When the background is a daytime cloud, the resulting phototube current may be greater than 10^6 times the signal current which can be obtained from a projector of reasonable size and of moderate power consumption.

Because of the relatively high brightness of daytime clouds, it is possible, if the phototube has very little or no granular noise[3, 5], to design the phototube and amplifier circuit so that all other associated noises are negligible compared to the shot noise of the phototube. This may be done without reducing the ratio of signal to shot noise and hence the ratio of signal to total noise is increased. The reason is as follows: For any infinitesimal frequency interval, the theoretical ratio of the mean-square shot noise of the phototube to the mean-square thermal noise of the circuit coupling the phototube to the first stage of the amplifier is given by[4]

$$\frac{eI_g Z^2}{2KTR} \tag{1}$$

where e = charge on the electron, I_g = phototube current, K = Boltzmann's constant, T = absolute temperature, Z = impedance of the coupling circuit for the frequency of the interval, and R = real part of the impedance (neglecting tube capacities, $Z = R$ for direct coupling). Thus, if Z^2/R is made sufficiently large, the shot noise becomes predominant for a given phototube current; and if R is large enough, the thermal noise will exceed the tube noises of the first stage. If, for a narrow band amplifier, Z is considered to be independent of frequency, the signal and the shot noise are proportional to Z. Hence it follows that no sacrifice is made in the ratio of signal to shot noise by increasing Z until the shot noise predominates above the other noises.

The problem of detection is further complicated by the large variations in the background brightness which arise from the motion of the clouds across the beam of the projector, changes in the formation of the clouds, and fluctuations in the amount of daylight incident on the clouds. In order that the total light received will have a detectable modulated component resulting from the projector, the frequency of modulation of the beam must not be too low; otherwise the random variations in the background light will obliterate the signal.

In continuation of Middleton's initial work, the Canadian Westinghouse Company used mechanical modulation at a frequency of 400 cycles per second. The precision with which the parts had to be made and the difficulties encountered with bearing failures because of the high speeds required, indicated that the recently developed high-intensity mercury-arc lamps might prove to be a better means of obtaining a modulated beam. When these lamps are operated on 60-cycle current the modulation is approximately 95 per cent[6] and has a frequency of 120 cycles per second. Although this frequency is less than that used by the Westinghouse Company, it is sufficiently high to overcome the effect of the relatively slow variations of the background light. Recent tests show, however, that this is about the minimum frequency that can be used.

b. Projector

The projector consists of a 1000-watt, water-cooled A-H6 lamp[6] located at the focus of a 24-inch parabolic mirror having a focal length of 10 inches. The dimensions of the mercury arc are approximately $^{3}/_{50}$ inch by 1 inch. The optical axis of the mirror is vertical and the lamp is mounted horizontally so that the longest dimensions of the spot on the base of the cloud is perpendicular to the geometrical plane determined by the beam and the detector. Since the detector must scan the base of the cloud to locate the spot, this arrangement decreases slightly the accuracy with which the optical axis of the detector must coincide with the exact center of the beam during the scanning process. Likewise it is the narrow dimension of the spot that will be traversed and a more precise determination of the angular elevation results.

c. Phototube and Optical System of the Detector

Since the signal is proportional to the signal light received and the shot noise is proportional to the square root of the background light received, the field of view of the detector should include the entire spot, but no more, in order to obtain the maximum signal to noise ratio. Practically, the entire spot is difficult to define. The brightness of the mercury arc[6] is greatest at the center and falls off rapidly at the edges. Imperfections in the mirror of the projector, aberrations, and irregularities in the base of the cloud also tend "to smear" the spot. Probably the most important consideration is the change in the projected area of the spot on a plane perpendicular to the optical axis of the detector as the angular elevation of the spot varies with cloud height.

A diaphragm located at the focus of a lens provides a simple optical system having light gathering properties and a restricted field of view. For this arrangement the phototube is placed behind the diaphragm. The light rays after passing through the diaphragm are divergent, and if all these rays are to be intercepted by the cathode of the phototube, the focal length of the lens that can be used is determined by the cathode dimensions, the distance between the diaphragm and the cathode, and the aperture of the lens. To a first approximation, the diaphragm opening required to limit the field of view to the spot is equal to the size of the source multipled by the ratio of the focal length of the lens of the detector to the focal length of the mirror in the projector.

In choosing a phototube one is limited to the vacuum type because of the greater shot noise associated with the gas-filled types for the same phototube current.[7] Barrier-layer photocells cannot be used because their voltage sensitivity is reduced to practically zero for high flux density. If the phototube is sensitive only to the wave-length interval of the signal light, the effective background light is reduced and hence the signal to noise ratio is increased. The spectral response of the RCA 929 phototube[8] matches the spectral distribution of the light from the A-H6 mercury-arc lamp exceedingly well. Its sensitivity is greater than that of the average gas-filled phototube and tests have failed to indicate the presence of any granular noise. The dimensions of the cathode are approximately $^{7}/_{8}$ inch by $^{11}/_{16}$ inch.

The final optical arrangement used consisted of an 8-inch plano-convex glass condensing lens, a diaphragm having a slit opening approximately $^{3}/_{25}$ inch by $^{11}/_{16}$ inch with the longest dimension horizontal, and the 929 phototube mounted horizontally as close behind the diaphragm as possible. The specified focal length of the lens is 19 inches but, because of the severe chromatic aberration, the diaphragm was located about 17 inches from the convex surface which corresponds approximately to the focal length for blue light. The long dimension of the diaphragm is equal to the maximum dimension of the cathode surface and the other dimension was chosen in accordance with the previous discussion. The optical system is mounted so that it may be rotated about a horizontal axis in order to scan the base of the cloud for locating the spot. Phototube currents as high as 25 microamperes have been obtained when the detector is directed at clouds illuminated by direct sunlight and currents as low as 2 microamperes result from dark overcast daytime clouds. The detector was located about 1000 feet from the projector.

d. Amplifier

The phototube and 120-cycle, resistance-capacitance

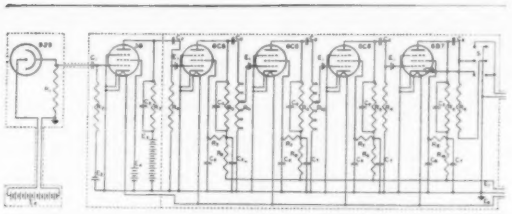

FIG. 1. Wiring diagram of phototube and 120-cycle, resistance-capacitance tuned amplifier having the following circuit constants:

	Microfarads		*Volts*
C_1	0.0000125	E_1	1.0 (Mallory grid bias cell)
C_2	0.00025	E_2	270
C_3	0.002	E_3	1.5
C_4	0.0055	E_4	4.5
C_5	0.004	E_5	45
C_6	0.1	E_6	6
C_7	2.0	E_7	135
C_8	0.25		

	Megohms		*Megohms*		
R_1	10	R_{11}	5.1 (17 equal steps)		
R_2	100	R_{12}	5.05		
R_3	1	*Individual steps (megohms)*			
R_4	5		0.00005	0.003	0.2
R_5	0.25		0.0001	0.006	0.4
R_6	0.5		0.0002	0.012	0.75
R_7	4.3		0.0004	0.025	1.5
R_8	6		0.0008	0.05	2.0
R_9	1.4		0.0015	0.1	
R_{10}	0.08				

S—DP-DT switch

tuned amplifier circuit[9,10] are shown in Fig. 1. A 5-foot, flexible, shielded cable having a capacitance of 26 $\mu\mu f$ per foot connects the phototube to the amplifier. This cable, the blocking capacitor C_1, the phototube-load resistor R_1, and the grid-leak resistor R_2 make up the coupling circuit between the phototube and the first stage. The blocking capacitor is required to prevent the variations in the background light from changing the bias on the first stage. The maximum impedance of the coupling circuit that can be used practically, and consequently the maximum initial signal that can be obtained is limited by the dynamic grid impedance of the tube of the first stage. The 38-type tube has a high dynamic grid impedance since the grid current, for the voltages used, is less than 10^{-11} ampere.[3] The choice of this tube permits the use of a 10^8-ohm grid leak R_2. Under these operating conditions the grid current shot noise is negligible. The values of the component parts of the coupling circuit fulfill the conditions required by Eq. (1) for shot noise predominance and also sharpen the tuning of the amplifier. It was found necessary to use for C_1 a capacitor having a leakage resistance greater than 10^{12} ohms to keep the grid bias constant. At 79 and 180 cycles the amplification of the amplifier is 0.707 times the maximum amplification at 120 cycles.

The diode part of the 6*B*7 tube is used in conjunction with a d.c. meter for checking the operation of the amplifier, for making noise measurements and for studying the effects of the varying background light. As used, the amplifier and phototube are operated with batteries. Since the fundamental ripple frequency of a full-wave rectifier is 120 cycles, a.c. operation may prove to be troublesome. In this connection, the total plate and screen currents for the five stages is less than 1 milliampere. It is believed that this small current will make possible the design of an a.c. power supply for the plate and screen voltages by using a resistance-capacitance filter to reduce the 120-cycle ripple considerably below the signal. A power supply of this type has been used satisfactorily for the phototube.

e. Output Circuit and Meter

According to Johnson,[10, 3] for an amplifier having a uniform amplification between the frequencies f_1 and f_2 and zero elsewhere, the smallest steady signal E_s that can be detected in the presence of a statistical noise voltage E_n is given by

$$E_s = (5\lambda/(f_2 - f_1))^{1/2} E_n \tag{2}$$

where λ is the decay constant of the output meter. Also, for direct coupling of the phototube to the amplifier, the input noise level of the coupling circuit and the amplifier is given by

$$\overline{E_n^2} = 4KT\{[1/(2\pi C)] \times (\tan^{-1}[2\pi RC(f_2 - f_1)/(1 + 4\pi^2 R^2 C^2 f_1 f_2)]) \times (1 + 19.4 I_g R) + R_i(f_2 - f_1)\} \tag{3}$$

where K = Boltzmann's constant, T = absolute temperature, C = sum of static and dynamic input-capacities, R = the phototube load resistance, I_g = sum of the phototube current and the grid current from the input tube, and R_i = equivalent noise resistance of the input tube. Replacing the arc-tangent by its argument (which increases the value for the noise slightly)

$$\overline{E_n^2} = 4KT(f_2 - f_1) \times [R_i + R\,(1 + 19.4 I_g R)/(1 + 4\pi^2 R^2 C^2 f_1 f_2)] \tag{4}$$

For $R = 10^7$ ohms, $C = 1.3 \times 10^{-10}$ farad, and $I_g \geq 2 \times 10^{-6}$ ampere, $19.4\, I_g R >> 1$ and $19.4\, I_g R^2/(1 + 4\pi^2 R^2 C^2 f_1 f_2) >> R_i$ where R_i is about 5×10^4 ohms.[3] Hence Eq. (4) may be written as

$$\overline{E_n^2} = 77.6KT\,(f_2 - f_1) I_g R^2/(1 + 4\pi^2 R^2 C^2 f_1 f_2) \tag{5}$$

The signal-voltage squared E_s^2 resulting from the root-mean-square signal-current I_s in the phototube is given by

$$E_s^2 = I_s^2 R^2/(1 + 4\pi^2 f_0^2 R^2 C^2) \tag{6}$$

where f_0 is the modulation frequency of the signal light.

If the percentage band width of the amplifier is comparatively small, that is, if

$$(f_2 - f_1)/(f_1 f_2)^{1/2} \lessapprox 1 \tag{7}$$

then

$$f_0^2 \doteq f_1 f_2 \tag{8}$$

and the ratio of signal to noise from Eqs. (5) and (6) is given by

$$E_s/E_n = I_s/[(f_2 - f_1)(77.6\ KTI_g)]^{1/2} \tag{9}$$

Equating E_s/E_n from (2) and (9), the minimum root-mean-square signal-current that can be detected is given by

$$I_{s_{min.}} = (388\lambda\, KTI_g)^{1/2} \qquad (10)$$

This equation, based on Johnson's original Eqs. (2), (7) and (8) is contrary to the accepted idea, namely, that the minimum detectable signal current is proportional to the square root of the band width.[4, 7, 11, 12] As pointed out by Johnson, Eq. (10) shows that $I_{s_{min.}}$ does not depend on the band width if the band width is sufficiently narrow to satisfy Eq. (7), but depends on the decay constant of the output meter; that is, the minimum detectable signal is inversely proportional to the square root of the period of the output meter.

If it is assumed that the band width of the amplifier of Fig. 1 is 101 cycles (that is, $f_1 = 79$ cps. and $f_2 = 180$ cps., the frequencies at which the amplification is 0.707 times the amplification at 120 cps.) Eq. (7) is satisfied. Furthermore, the approximations that must be made to obtain Eq. (5) when using the complex impedance for the coupling circuit introduce an error which is the same order of magnitude as that used above. The case for direct coupling is given for simplicity.

The above discussion is valid for noises which are constant except for statistical fluctuations. But during the time the base of the cloud is being scanned to find the spot, the output current will be varying in general by an amount greater than that which will result when the spot is located even if a long-period meter is used to damp out almost completely the statistical fluctuations. This results from the variations in the background brightness of the clouds as stated before and, even more so, from the change in brightness from cloud to cloud as the scanning is made. If, however, a 120-cycle synchronous commutator, which is phased with the signal, is introduced between the amplifier and the meter, the average output current in the absence of the signal will be zero because of the random phase of the shot noise. Thus the variations in brightness will not give a false indication of the signal since the same average zero reading will be obtained for the shot noise whether the average phototube current is 25 microamperes or 2 microamperes. A second advantage results because effectively an increased scale length can be used. Normally the shot noise would produce an average reading 10 to 100 or even 1000 times that resulting from the signal but by reducing the average noise-output current to zero the entire scale of the meter can be used for indicating the signal.

There is a practical limit for the maximum period of the meter that can be used. If the scanning is made at a reasonable rate and if the period of the meter is too long, the spot will be passed without obtaining a noticeable indication. A period greater than 1 minute has been found to be unsatisfactory.

An "electronic switching-circuit," which performs the same function as a synchronous commutator, is shown in Fig. 2. The rectified, but non-filtered, output of the transformer T_1 is the plate-supply for the 6J7 tube. If the resistance R_4 is correctly adjusted the plate current consists of square-topped pulses which are maintained for approximately $^1/_{240}$ second. The time-average of the IR drop across the plate resistor R_3 can be obtained from the potential across the capacitor C_2 and this potential is reasonably steady because of the long period of the series circuit consisting of R_2 and C_2. Furthermore, the magnitude of this potential is almost completely independent of the amplified shot noise from the amplifier because of the random phase as in the case of a synchronous commutator. But when a sustained and phased 120-cycle signal is added the potential across C_2 increases or decreases depending on whether the positive or negative portion of the signal is present during the time the plate current is flowing. A previous switching circuit contained a phase-shifting element in front of the primary of the transformer T_1, but it so happens that it is not needed because the positive portion of the signal is correctly phased to within a few degrees when the transformer for the mercury-arc lamp in the projector is connected to the same alternating-current supply. The remainder of the circuit shown in Fig. 2 is essentially a vacuum-tube voltmeter which is used to indicate the change in the potential across C_2.

In practice, the potentiometer R_5 is adjusted to give a plate current of about 7 milliamperes. In general, this current will be fluctuating by about 0.5 milliampere. If, during the scanning process to find the spot, the current drops to less than 6 milliamperes, one can be sure that the spot has been located. When

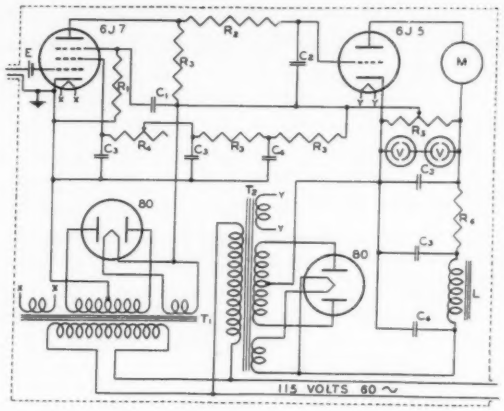

FIG. 2. Wiring diagram of output circuit and meter having the following circuit constants:

Microfarads		*Megohms*	
C_1	0.0001	R_1	20
C_2	4	R_2	3
C_3	40	R_3	0.1
C_4	4	R_4	0.1
		R_5	0.2
		R_6	0.003

T_1—830 volts a-c CT. T_2—700 volts a-c CT
E—1.25 volts (Mallory grid bias cell)
L—15 henries at 85 milliamperes
M—0–10, d-c milliammeter
V—VR-150 voltage regulator tube

the signal is so weak that the decreased reading fluctuates about this point (6 milliamperes) the detection can be verified by repeating the traverse to make sure that a spurious indication had not been obtained.

Results

During the daytime, dark overcast clouds at an elevation of 9000 feet have been readily detected with the equipment described. For cumulus clouds illuminated by direct sunlight and having elevations up to 4000 feet, the detection is positive.

In the laboratory, measurements have been made to determine the minimum signal which can be detected with certainty in the presence of shot noise. Battery-operated incandescent lamps were used to simulate the background light and were arranged to give a phototube current of 5 microamperes. A sector disc driven by a synchronous motor was placed between a small flashlight lamp and the phototube to obtain a 120-cycle chopped signal. The flashlight lamp was located finally about 80 feet from the phototube. The resulting signal light was about 5×10^{-7} times the background light and according to Eq. 10 the signal current was less than 2 times the theoretical minimum.

Discussion

There are several possibilities for increasing the sensitivity of the equipment. Among the most obvious are the use of a larger mirror in the projector to give a more intense beam of light and the use of a larger lens in the detector. The latter possibility would increase the flux density on the cathode of the phototube to such an extent that it might be excessive and destroy the photosensitive surface. If the signal could be restricted to a single wave length it is conceivable that the background light could be reduced to a negligible factor by using filters which transmit the signal light and only a very small part of the background spectrum. The high-intensity mercury-arc lamp is the only practical source of high brightness having a considerable percentage of its energy emitted in narrow wave-length intervals. But to take advantage of this, one requires filters which have narrower transmission bands than are now available. Many filter combinations have been tried but a net loss was obtained rather than a gain in the signal to noise ratio, because the signal is proportional to the transmission of the filter whereas the shot noise resulting from the background light is proportional to the square root of the transmission.*

* Let I_s and I_g be the phototube currents resulting from the signal light and the background light, respectively. Then the ratio of signal to noise E_s/E_n may be written as $kI_s/I_g^{1/2}$. If a filter is introduced the ratio of signal to noise becomes $kI_sT_s/(I_gT_g)^{1/2}$ where T_s and T_g are the respective transmission factors based on the spectral response of the phototube for the signal light and for the background light. Hence $T_s/T_g^{1/2}$ must be greater than unity in order to increase the signal to noise ratio.

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INSTITUTE OF THE AERONAUTICAL SCIENCES
HONORS NIGHT & ANNUAL DINNER
HOTEL BILTMORE JANUARY 28, 1941
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Honors Night and Annual Dinner, Institute of the Aeronautical Sciences, Hotel Biltmore, New York, January 28, 1941

Institute of the Aeronautical Sciences Honors Night Dinner

THE annual Honors Night Dinner of the Institute was held on Tuesday, January 28, 1941, the evening preceding the three days of technical sessions of the Ninth Annual Meeting. Eight hundred members and guests of the Institute, including leaders in the aeronautical sciences, the aviation industry and aeronautical departments of the government attended this annual presentation of the awards and honors of the Institute. The Grand Ballroom of the Hotel Biltmore in New York, where the Dinner was held, was decorated with an exhibit from the collection of aeronautical prints, posters and sheet music presented by Mrs. Bella C. Landauer to the Aeronautical Archives.

Major James H. Doolittle, retiring president of the Institute, acted as toastmaster and opened the program with a greeting to members and guests. With the following program of presentations, excerpts are given from the addresses of the speakers. The full text and citations of the awards will be found in the reproductions of the certificates published herewith.

Greeting by the President of the Institute

MAJOR DOOLITTLE: As president of the Institute, I welcome you to our annual Honors Night Dinner when we bestow awards upon many who are making outstanding contributions to the advancement of aeronautics.

This annual dinner has established certain precedents which we always try to follow: First, that the speaking program must be over before dawn! Last year, many who were with us felt that we had not been fair and that we cut off the speaking too soon. The program was so short that some people had to waste their time visiting with old friends. This year we plan to have longer speeches. They should last at least three minutes and not over five.

The second precedent is that the Dinner Committee and officers of the Institute arrange the tables while blindfolded so that they show no favoritism. That explains why you all do not have ringside seats.

Another precedent, and one which has added a decorative feature to the Dinner, is that we invite as our guests a few of the loveliest and most attractive ladies we can find, and place them before us in the balcony where we may see them and let their charms shine down on us.

Still another precedent is the abolition of the speakers' table. This was so successful last year that we shall always let our speakers and guests enjoy themselves at the floor tables instead of being exhibits A to Z on a dais.

Thus we do our best to make this dinner different from others and possibly that is why it has become the outstanding aviation function of the year.

I suppose that here is my opportunity to introduce a little propaganda for the Institute and to crow a little over its growth, to tell you how solvent it is and spread before you its many accomplishments. But I shall save all this for the Annual Meeting tomorrow when we will report to members. Nine years is a very short period to establish any society as firmly as the Institute. We believe that it is better to let the evident confidence of our benefactors and the generous support of the whole aircraft industry speak for us.

The Daniel Guggenheim Medal for 1940

Awarded to Glenn L. Martin, Hon. D.Sc.; Dr. Eng.; Hon. F.I.Ae.S.; President, The Glenn L. Martin Company.

Presented by Dr. J. C. Hunsaker, Massachusetts Institute of Technology.

DR. HUNSAKER: The career of Glenn Martin is one of the most successful, as well as one of the longest in American aviation. It has been my good fortune to have had an opportunity to follow it from the early days when he designed and built his first plane in California and taught himself to fly.

One of his earliest flights was an over-water flight from the coast south of Los Angeles to Santa Catalina Island. It was a world record then. Three years ago he repeated this flight in one of his great China Clippers to celebrate the Twenty-Fifth Anniversary of that remarkable flight.

He has built airplanes continuously for a lifetime and he has built practically every type—land planes, seaplanes and flying boats, torpedo planes, military, naval and commercial. His great clippers have set new standards for transoceanic aircraft,

Glenn L. Martin (left), recipient of The Daniel Guggenheim Medal for 1940, being congratulated by Dr. J. C. Hunsaker (*Wide World photo*).

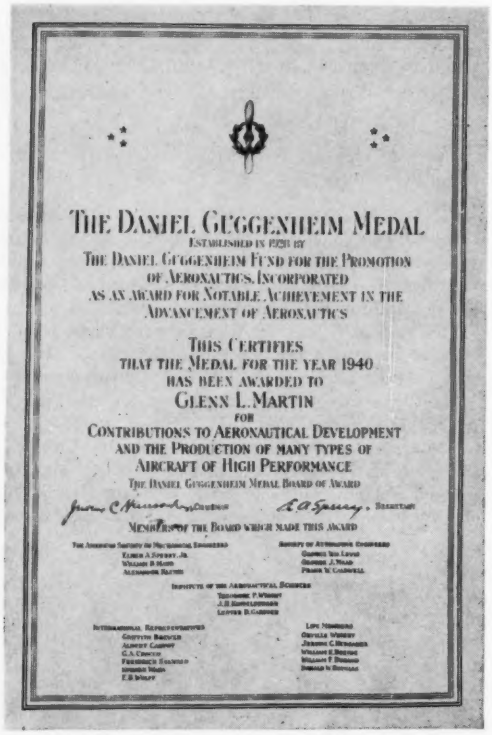
but I think myself, that he will be remembered longer for the bombers. We all remember—those who are old enough—the Martin Bombers of 1918 which appeared in the war. I think that was the first military aircraft developed entirely in this country. It was a very successful machine, far in advance of the contemporary European bombers that we were trying to put into production at that time. These European types never got much beyond the "on order" stage.

Martin has continued with bombers; to make them faster, larger and more powerful and we are proud to know that Martin Bombers, in this present war, are reported as superior—in their class—to any operating in those areas. It is no secret that Glenn Martin is always developing still more advanced types. I predict that we shall soon hear of American bombers that can keep

our enemy at arm's length and punish him at a distance far from our own shores.

At Baltimore, Glenn Martin has built a great factory where he directs the work of many thousands of employees. This factory is a monument to his great courage during the hard times and to his ability to sense the shape of things to come.

The Daniel Guggenheim Medal is presented to him for a career of service to the advancement of American aeronautics.



THE DANIEL GUGGENHEIM MEDAL

ESTABLISHED IN 1929 BY

THE DANIEL GUGGENHEIM FUND FOR THE PROMOTION OF AERONAUTICS, INCORPORATED AS AN AWARD FOR NOTABLE ACHIEVEMENT IN THE ADVANCEMENT OF AERONAUTICS

THIS CERTIFIES THAT THE MEDAL FOR THE YEAR 1940 HAS BEEN AWARDED TO

GLENN L. MARTIN

FOR

CONTRIBUTIONS TO AERONAUTICAL DEVELOPMENT AND THE PRODUCTION OF MANY TYPES OF AIRCRAFT OF HIGH PERFORMANCE

THE DANIEL GUGGENHEIM MEDAL BOARD OF AWARD

MEMBERS OF THE BOARD WHICH MADE THIS AWARD

MR. MARTIN: I have been thinking back over the short span of years since my first efforts at flying. My first airplane weighed 850 pounds. It had 15 horsepower and 10 minutes fuel capacity. The next step was a 30 horsepower engine in a ship weighing 1150 pounds. That one would stay up for 25 minutes. But the real advance began with 60 horsepower, fuel for one hour, and a carrying capacity of 300 pounds. This plane weighed about 1350 pounds.

Since then, there has been a rapid and steady growth toward more horsepower, toward refinements in aerodynamics. During the first World War, we had some very fast planes that were making up to 150 miles per hour. Bombers, for the first time, flew faster than 100 miles per hour. Ten years ago bombers were first designed to exceed 200 miles per hour and carried 2400 pounds of bombs. Commercial ships were then developed to carry heavy loads and their power was constantly increasing. Today, a medium bomber will weigh about 23,000 pounds, will have 4000 horsepower and carry its load over thousands of miles at speeds well above 300 miles per hour.

I need not give you exact figures on any of today's airplanes. But ten years ago, the China Clipper and its sister ships that we designed weighed over 50,000 pounds. They were the first of the large cargo carriers for over-ocean service. There are many reasons why commercial aeronautics is with us to stay. Let me cite one reason. The China Clippers, even now, will make one mile on one gallon of gas; 6 pounds of fuel will move over 50,000 pounds of airplane one mile at a rate of 150 miles per hour. That ratio of efficiency exceeds any other means of transportation. But that airplane was designed ten years ago. Today, airplanes are being built that weigh 140,000 pounds, have 8000 horsepower and will carry 14,000 to 20,000 pounds of disposable load, be it bombs or cargo, much farther than the China Clipper.

The people set the rate of speed for the advancement of aeronautics. We advance only as fast as the market requires the service or as the national defense problems require the airplanes. The aircraft industry in the United States has adequate research and engineering facilities to keep well ahead of that demand. Patronage and volume will always set the rate of advance. We, the industry, are ready for still greater ships that go far beyond the abilities of today's airplanes.

For instance, we have a design that I referred to publicly, for a ship weighing 250,000 pounds. It is a flying boat which can carry 80,000 pounds of bombs a distance of 3700 miles or 40,000 pounds of bombs a distance of 7000 miles. It has a speed in excess of 300 miles an hour. As a commercial plane, it has a ton-mile efficiency that makes it possible to actually compete with surface shipping. We are within striking distance of freight and express by air, and we will have it just as soon as the public is ready to use the service and make available the volume necessary to justify the expense of developing and building these airplanes.

I am enjoying the continuation of aeronautical development—it is rapid and it is something that, to me, is all-consuming. One doesn't care, under such circumstances, to do anything else but build better and faster airplanes.

THE SYLVANUS ALBERT REED AWARD FOR 1940

Awarded to Hugh L. Dryden, Ph.D.; Hon. F.I.Ae.S.; A.F.R.Ae.S.; Chief of the Mechanics and Sound Divison, National Bureau of Standards.

Presented by Dr. G. W. Lewis, Director of Research, National Advisory Committee for Aeronautics.

DR. LEWIS: For many years, aeronautical scientists have discussed and studied the principles and the mechanics of boundary layer flow. Progress has been rather slow. You will all recall Mark Twain's famous remark: "Everybody talks about the weather, but no one does anything about it." Dr. Dryden has done something about it. He has studied the nature of flow and the boundary layer.

Dr. George W. Lewis (left) presenting The Sylvanus Albert Reed Award to Dr. Hugh L. Dryden (*Wide World photo*).

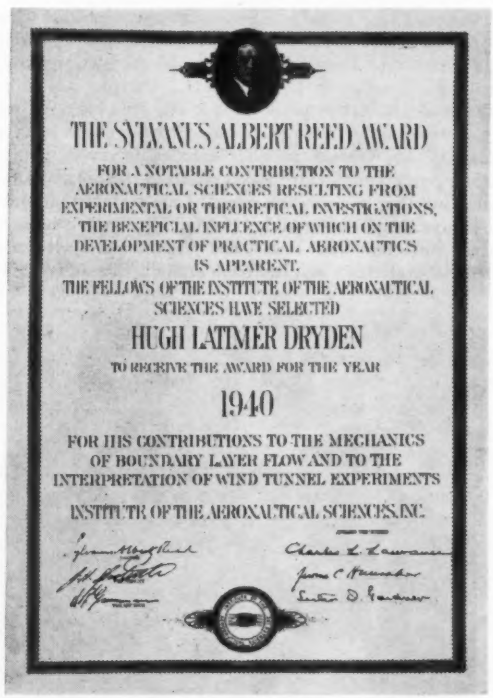
What is this boundary layer and how does it affect the speed and efficiency of the airplane?

The air, in flowing over a wing, starts at the leading edge. The boundary layer of air is only a few thousandths of an inch

thick. Not far from the leading edge of the wing there is a change in the flow, a transition from the smooth laminar flow to turbulent flow, like the rough and tumble flow of water over stones in a swift stream. The flow remains turbulent, the boundary layer increases in thickness until it is about an inch thick, or deep, at the trailing edge of the average wing. But what we would like to obtain is a smooth laminar flow over the surfaces of the wing, from the leading edge to the trailing edge, thus greatly increasing the speed and the range of the airplane.

To study what happens in the boundary layer, the nature of the change from laminar to turbulent flow, Dr. Dryden developed the hot wire anemometer into an instrument for accurately determining fluctuations of the air flow in the boundary layer and the meaning of the disturbance of the flow. This wire anemometer is so fine that it can scarcely be seen with the naked eye.

The increased understanding of the mechanics of the boundary layer flow has resulted so far in the development, in the wind tunnel, of an airplane wing of greatly increased efficiency. Dr. Dryden's work is a notable fundamental contribution to the attack on the general problem of controlling the boundary layer flow.


THE SYLVANUS ALBERT REED AWARD

FOR A NOTABLE CONTRIBUTION TO THE AERONAUTICAL SCIENCES RESULTING FROM EXPERIMENTAL OR THEORETICAL INVESTIGATIONS, THE BENEFICIAL INFLUENCE OF WHICH ON THE DEVELOPMENT OF PRACTICAL AERONAUTICS IS APPARENT.

THE FELLOWS OF THE INSTITUTE OF THE AERONAUTICAL SCIENCES HAVE SELECTED

HUGH LATIMER DRYDEN

TO RECEIVE THE AWARD FOR THE YEAR

1940

FOR HIS CONTRIBUTIONS TO THE MECHANICS OF BOUNDARY LAYER FLOW AND TO THE INTERPRETATION OF WIND TUNNEL EXPERIMENTS

INSTITUTE OF THE AERONAUTICAL SCIENCES, INC.

DR. DRYDEN: I am deeply appreciative of the action of the Fellows of the Institute in electing me to receive the Reed Award for 1940. They had in mind, of course, the accomplishments of the group with which I have been privileged to work in attempting to increase our fundamental knowledge of air flow. I am but the symbol of and spokesman for that group.

You have already given me the opportunity on another occasion of telling you something of the general nature of our work and its results. Fortunately you do not now require me to justify the wisdom of your selection by giving some further accounting. This is not the time or place to discuss technical matters.

I think that the influence of such awards as the Reed Award on the development of the aeronautical sciences is often underestimated. Recognition by one's associates always brings great pleasure and is a decided stimulus to put forth greater efforts. The existence of prospective awards influences, consciously or unconsciously, every worker in the field. The effect on a recipient is quite definite. One wonders why the honor is conferred upon him and resolves that, since his associates believe he is capable, he will really try to make some contribution to knowledge to justify their confidence in him. All of us on whom you have conferred this great distinction will give a little extra measure of effort and enthusiasm.

The contribution to aeronautics of Mr. S. A. Reed, whom I had the pleasure of knowing, is thus not limited to his personal work, but lives on through the impetus given year after year by the Reed Award.

The Octave Chanute Award for 1940

Awarded to Howard R. Hughes, M.I.Ae.S.; pilot of the round-the-world flight in 1938 and numerous other record breaking flights.

Citation by Colonel F. P. Lahm, Air Officer, First Army Headquarters, U.S. Army.

COLONEL LAHM: The creation of awards in memory of great pioneers of American aeronautics is a most fitting way of honoring their work. No honor that has come to the Wright brothers will be more permanent than the Wilbur Wright Lecture which is given each year before the Royal Aeronautical Society and the Wright Brothers Lecture which is given before the Institute each year on December 17th.

Octave Chanute was a friend of the Wrights and did much to encourage them when they met with discouraging obstacles. It was my pleasure to meet and know him in 1908 and 1909 during the acceptance tests of the Wright airplane purchased by the Army. His visits at Fort Myer and his keen interest in the work of the Wrights resulted in the success of their first public demonstration in the United States. He was a great civil engineer who, for many years, was perhaps the most distinguished American of scientific attainments to have confidence in the ultimate success of man's efforts to fly. He was a true torch bearer in a world of unbelieving darkness. It is most appropriate that each year on Honors Night his great contributions to aeronautics should be recalled by the presentation of this award.

The recipient of the Octave Chanute Award for 1940 was not selected for his remarkable achievements in establishing world record flights. It was not because he has made outstanding speed, distance and endurance records that he was selected. There are other honors that have come to him for that part of his aviation career.

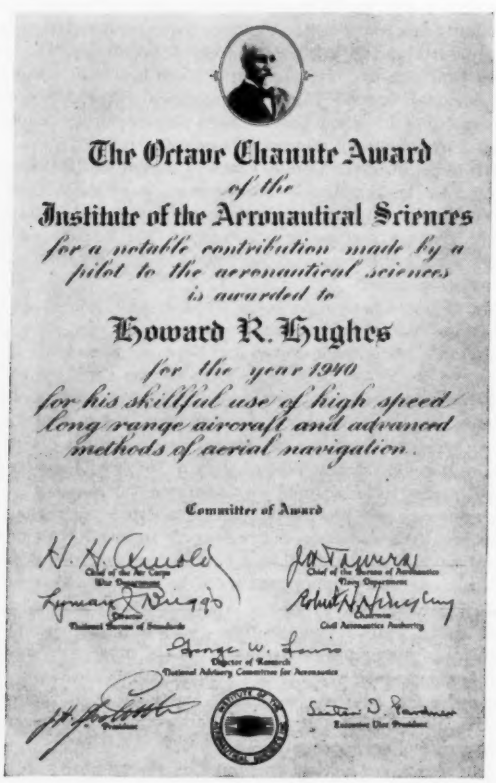
The Octave Chanute Award is given to pilots who make contributions to the aeronautical sciences. Last year, that great test pilot, Eddie Allen, received it. Everyone knows how he has advanced the design of aircraft. He was on the Award Committee who surveyed the field last year and it was his considered opinion that Howard Hughes had made the greatest contribution of the year to flying technique through his persistent determination to develop the best type of airplane for special uses and his unwillingness to be satisfied with anything that was not as near perfection as was procurable. He stimulated progress by demanding better and better performance. In his effort to improve aerial navigation, he developed new meteorological procedures. What was equally important, when he was sure that he had pushed aeronautical design and equipment to its most advanced stage, he then did his own testing. I am told that when he took delivery of his first high altitude plane, he made sixty take-offs and landings under every possible combination of load and speed. He never left anything to chance and because of this careful testing, he has been able to bring to the United States an enviable record of achievement.

I have received a telegram from him which I shall read:

"UNFORTUNATELY I HAVE BEEN FORCED TO REMAIN HERE IN CALIFORNIA AND CANNOT ATTEND THE HONORS NIGHT DINNER, BUT I WANT TO SEND MY VERY DEEP APPRECIATION FOR THE OCTAVE CHANUTE AWARD. MY BEST WISHES FOR A MOST SUCCESSFUL OCCASION.

HOWARD HUGHES"

Howard R. Hughes, recipient of The Octave Chanute Award.



The Octave Chanute Award
of the
Institute of the Aeronautical Sciences
for a notable contribution made by a pilot to the aeronautical sciences is awarded to
Howard R. Hughes
for the year 1940
for his skillful use of high speed long range aircraft and advanced methods of aerial navigation.

Committee of Award

I am sure that all those present will join with me in wishing him a speedy recovery from the recent accident he has suffered. The Octave Chanute Award is presented to Howard Hughes with the compliments and best wishes of the members of the Institute and with the hope that it will stimulate him to add further to the fame of American aeronautics.

The Lawrence Sperry Award for 1940

Awarded to W. Bailey Oswald, Ph.D.; F.I.Ae.S.; Chief of the Aerodynamics Group, Douglas Aircraft Company.

Presentation by Dr. Clark B. Millikan, California Institute of Technology.

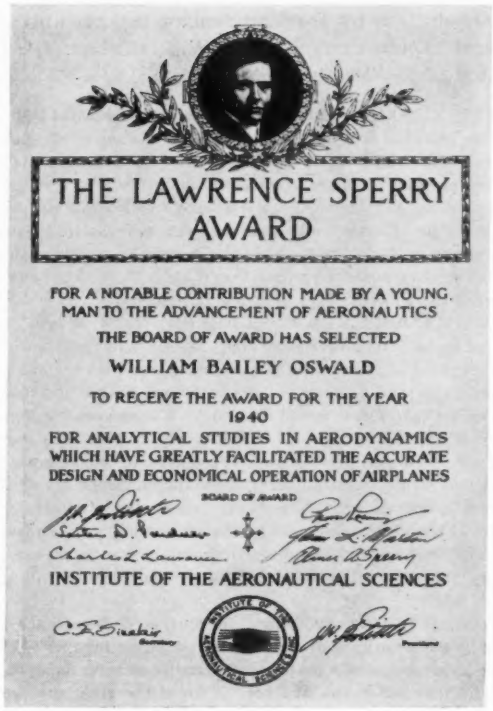
DR. MILLIKAN: It becomes increasingly clear that the salvation of our way of life lies primarily in the transformation of the most advanced and even abstract scientific and technical knowledge into effective and productive effort. Dr. Oswald's career exemplifies to a remarkable degree this coupling of scientific training and ability with actual productive achievement in the field of modern airplane development.

In outlining Dr. Oswald's professional history, a rather interesting parallel suggests itself. Last year, at the Institute Honors Night Dinner the Daniel Guggenheim Medal was presented to Donald W. Douglas by Dr. Hunsaker. Douglas was once one of the students in aeronautics under Dr. Hunsaker. Tonight, the situation—although several academic generations removed—is similar. Dr. Oswald, in 1928, enrolled in my first airplane course. As I recall, Dr. Hunsaker reported that he and Douglas learned together in their new roles. I am certain that this was true of myself and Dr. Oswald. Not only were new courses being started, but a new wind tunnel had just been completed and required elaborate tests and thorough study. Oswald contributed

Dr. W. Bailey Oswald (left) receiving The Lawrence Sperry Award from Dr. Clark B. Millikan (*Acme photo*).

greatly to the usefulness of this type of apparatus as well as formulas for aeronautical design. He very quickly demonstrated the characteristic thoroughness and passionate persistence for correctness and accuracy which marked all of his subsequent work.

Contributions for which Dr. Oswald is universally noted throughout aeronautical circles include his analytical performance studies in aerodynamics, which form the basis for much of the subsequent work in this field, his studies in cooperation with E. T. Allen in developing cruising formulas for controlling flight, which led the way for much of the modern airline technique, and finally his research and exhaustive studies on effective landing gear and airplane design.


THE LAWRENCE SPERRY AWARD
FOR A NOTABLE CONTRIBUTION MADE BY A YOUNG MAN TO THE ADVANCEMENT OF AERONAUTICS
THE BOARD OF AWARD HAS SELECTED
WILLIAM BAILEY OSWALD
TO RECEIVE THE AWARD FOR THE YEAR 1940
FOR ANALYTICAL STUDIES IN AERODYNAMICS WHICH HAVE GREATLY FACILITATED THE ACCURATE DESIGN AND ECONOMICAL OPERATION OF AIRPLANES
BOARD OF AWARD
INSTITUTE OF THE AERONAUTICAL SCIENCES

DR. OSWALD: I am very happy to receive the Lawrence Sperry Award and wish to express my gratitude to the Award Committee and to the donors of the award. This award is not a self-deserved honor in my case. In fact, I am a very fortunate young man. My education has always been fostered. My studies, my research work and my endeavors in the industry have been carried out under the most able and helpful direction. Many people in the industry, in the air lines, in the military services and in research institutions have given me help in many ways. My own loyal and most efficient group in aerodynamics at the Douglas Company has made possible many studies and findings that otherwise could not have been done.

I wish my friends to share with me the joy I have in receiving this award. In the future, I shall strive with every effort to add to the safety and economy of commercial flying and to the speed and effectiveness of military aircraft for the defense of our country.

The John Jeffries Award for 1940

Awarded to Louis H. Bauer, M.D.; F.A.C.P.; Cardiologist; Editor-in-Chief, "The Journal of Aviation Medicine"; Consultant in Aviation Medicine, Civil Aeronautics Administration.

Introduction by the President of the Institute and presentation by Dr. Herbert F. Fenwick, President, Aero Medical Association.

MAJOR DOOLITTLE: The Institute established last year a new award to stimulate and encourage outstanding work in the field of aviation medicine. It also honors an American who can truly be considered the first American to take an active interest in aeronautics. He and Benjamin Franklin were the first to recognize the importance of aerial navigaton, but Dr. John Jeffries, of Boston, actually went into the air to make scientific observations.

We had hoped that his great granddaughter, Mrs. J. H. Means, of Boston, could be here tonight to hand the award to Dr. Bauer, but she was prevented from doing so by illness. We have asked Dr. Herbert F. Fenwick, President of the Aero Medical Association, to present the award.

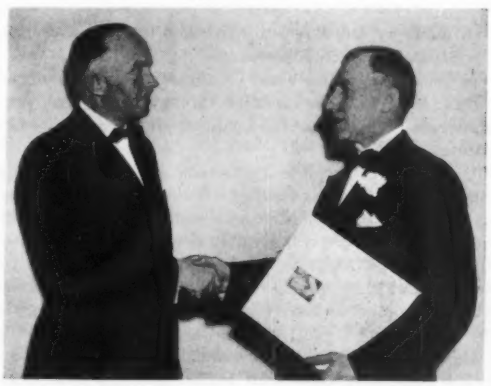
DR. FENWICK: It is most unusual for a member of the medical profession to be honored by any other group of scientists. The doctors usually get their honors only in their own societies. We feel doubly pleased—all of us in the Aero Medical Association—that this scientific body has made an annual award for stimulation of medical research.

There is only one man, as far as doctors and flight surgeons in this country believe, who should have the award this year, and I have the honor of presenting it to the father of aviation medicine of our country, Dr. Louis Hopewell Bauer.

Dr. Bauer graduated from Harvard Medical College. He then entered the Medical Corps of the Army in 1913. He was the first Commandant of the Army Air Corps School of Aviation Medicine, serving in this capacity from 1919 to 1925. While Commandant of this School, he organized the staff institute method of teaching. Further, it was only because of his great foresight and effort that it was designated in the Army General Staff as a Service School, which made it a permanent institution.

It is this same School of Aviation Medicine, founded by Dr. Bauer, that has carried through his tradition. Physicians now designated as Flight Surgeons are its graduates. At the present time the Army School of Aviation Medicine is graduating in the neighborhood of three hundred Flight Surgeons a year; while Dr. Bauer, in the first year, graduated two, if my history is right.

In 1926, Dr. Bauer wrote the first book on Aviation Medicine to be published anywhere in the world.



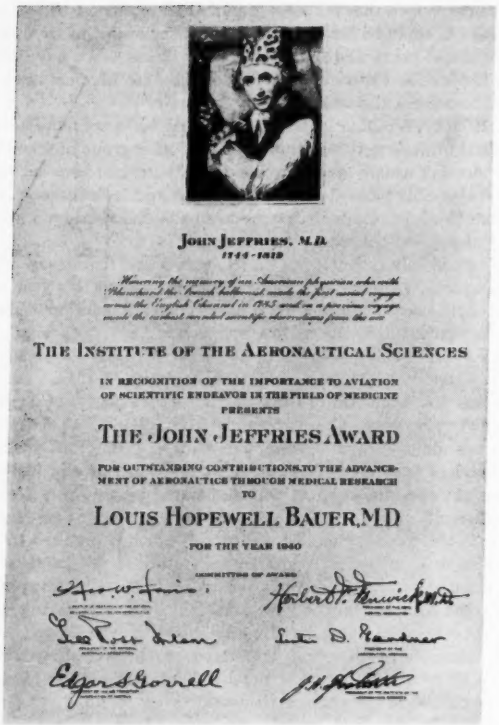
Dr. Herbert F. Fenwick (left) congratulates Dr. Louis H. Bauer on receiving The John Jeffries Award (*Wide World photo*).

In 1925, Colonel Bauer resigned from the Regular Army to accept the position of Chief of the Medical Section, Bureau of Air Commerce, Department of Commerce. He not only organized the Medical Section, but carried it through to a very high state of efficiency. Incidentally, the present physical examinations in both Army and civil aviation have changed very little over those which he originally set up.

In 1929, Dr. Bauer organized the Aero Medical Association of the United States and was elected its first president. In 1930, he launched a publication, "The Journal of Aviation Medicine," which was also the first of its kind in the world. He has edited this scientific publication since 1933 and now is its editor-in-chief.

He is a Lieutenant Colonel in the Medical Research Division of the United States Army Air Corps, Cardiologist for several hospitals and is Consultant in Aviation Medicine and Cardiologist to the Civil Aeronautics Administration.

The outstanding contributions to the advancement of aero-



JOHN JEFFRIES, M.D.
1744-1819

Honoring the memory of an American physician who with Blanchard the French balloonist made the first aerial voyage across the English Channel in 1785 and on a previous voyage made the earliest recorded aeorological observations from the air

THE INSTITUTE OF THE AERONAUTICAL SCIENCES

IN RECOGNITION OF THE IMPORTANCE TO AVIATION OF SCIENTIFIC ENDEAVOR IN THE FIELD OF MEDICINE PRESENTS

THE JOHN JEFFRIES AWARD

FOR OUTSTANDING CONTRIBUTIONS TO THE ADVANCEMENT OF AERONAUTICS THROUGH MEDICAL RESEARCH TO

LOUIS HOPEWELL BAUER, M.D.

FOR THE YEAR 1940

COMMITTEE ON AWARD

nautics made by Dr. Bauer are summed up in the citation for this presentation which I quote:

"For his pioneering work and continuing activity in advancing the interests of aviation medicine through twenty-one years of teaching, research, organization, editing and contributions to the literature."

DR. BAUER: Any of you who have stood in a similar place, I am sure, understand my feelings. To say that I feel honored at being the first recipient of this award sounds trite and inadequate, but it is difficult to express suitably one's appreciation.

The growth of Aviation Medicine can be compared to the growth of a child. Born during the first World War, it had a hectic but nonetheless lusty infancy. Then followed a period of sickly childhood; in fact, its life was despaired of. With the development of civilian air commerce, it took a new lease on life, although there were those who would cheerfully have strangled it. However, it gradually won friends and partisans. Today, those who frowned upon it most are its enthusiastic supporters.

To one who has followed its growth for over twenty years, it is a great satisfaction that as the child has become a man, it has been awarded its place in the sun and has been recognized as equally important with other aeronautical sciences. The satisfaction is all the greater in that this recognition has come not from the medical profession, which might be expected to foster it, but from the Institute of the Aeronautical Sciences which comprises all the professions concerned in aeronautics.

I accept this award, not as a personal tribute, but as a tribute to the farsightedness of those early workers, many of whom have passed on, and to the persistence of those who, during many years, have struggled to add their bit to air safety and who have had faith in Aviation Medicine.

THE ROBERT M. LOSEY AWARD FOR 1940

Awarded to Henry G. Houghton, Jr., M.S.; Fellow, A.A.A.S.; Assistant Professor of Meteorology, Massachusetts Institute of Technology.

Introduction by the President of the Institute and presentation by Commander F. W. Reichelderfer, Chief, United States Weather Bureau.

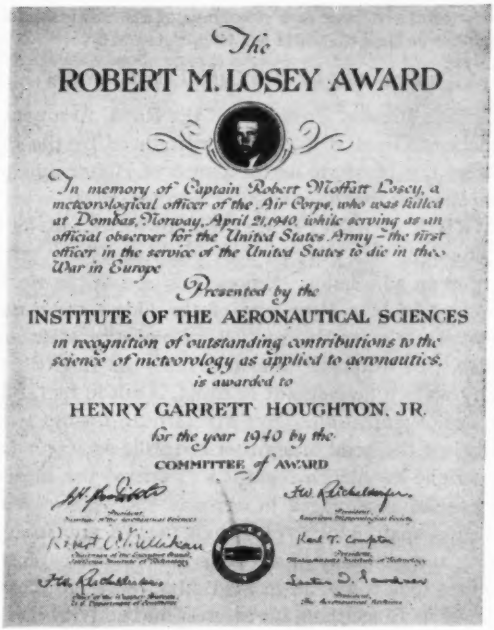
MAJOR DOOLITTLE: Another award established last year by the Institute was to encourage investigation in the field of meteorology which is so closely related to aviation. It was named in honor of a member of the Institute who lost his life while serving as a meteorological observer in Norway during the present war. No one could have been selected who could present this award with a better understanding of the scientific accomplishments of the recipient than Commander F. W. Reichelderfer, Chief of the United States Weather Bureau.

COMMANDER REICHELDERFER: Lord Kelvin is reported to have remarked once that the study of the atmosphere and its physical changes was too complex a subject for him. He preferred to stick to pure physics. If Lord Kelvin had foreseen the major role which would be taken by aeronautics in modern life and the supporting part which would be played by meteorology in the drama of aeronautical progress, he might have been intrigued rather than discouraged by the challenge of weather's secrets, even though its workings elude the confines of the physical laboratory and must be studied in the boundless free air. He might have added his talents to those of the pioneers who were struggling about that time to pull weather science out of its Dark Ages.

Fortunately for meteorology, the increased importance given to it by aeronautics is attracting an ever larger number of physicists to investigate its invisible physical reactions, the evidences of which we see in the weather. Two of the great problems in aeronautical meteorology and air navigation are ice accumulation on aircraft and the formation of fog. During the past twelve

Henry G. Houghton, Jr., (left) receives The Robert M. Losey Award from Comdr. F. W. Reichelderfer (*Acme photo*).

years a young engineer and physicist, first at the Round Hill Research Station and later in Cambridge, has devoted much of his attention to these dual problems, more particularly to the physical characteristics of natural fogs and their changes. His work has given to meteorologists new and basic knowledge on the size and distribution of water droplets which make up fog and the transmission of light through fog under natural conditions. He has not been content to accept fog as it is. With the sharp lance of his research he has tilted at that perennial monster of the would-be inventor—the artificial dissipation of fog—and has come out victorious. The method of fog dissipation, developed from the studies of this scientist and his collaborators, removes the fog, provided only that the apparatus is large enough and economy is not the main objective. His studies have pushed on into the


The
ROBERT M. LOSEY AWARD

In memory of Captain Robert Moffatt Losey, a meteorological officer of the Air Corps, who was killed at Dombas, Norway, April 21, 1940, while serving as an official observer for the United States Army – the first officer in the service of the United States to die in the War in Europe

Presented by the
INSTITUTE OF THE AERONAUTICAL SCIENCES
in recognition of outstanding contributions to the science of meteorology as applied to aeronautics,
is awarded to
HENRY GARRETT HOUGHTON, JR.
for the year 1940 by the
COMMITTEE of AWARD

field of cloud condensation processes and the formation of ice deposits from cloud droplets.

It is eminently fitting that Mr. H. G. Houghton, recipient of the Losey Award, is one whose researches and published works have brought him recognition as a leader in physical meteorology and whose contributions to the science apply so directly to aeronautics.

It is my privilege to present the Losey Award to Mr. Houghton with the citation:

"For fundamental research in physical meteorology on the processes of condensation in the atmosphere."

MR. HOUGHTON: I wish to express to the Award Committee and to the Institute my deep appreciation of the honor which you have bestowed on me in selecting me as the first recipient of the Robert M. Losey Award. Much of the credit for what we have accomplished in our studies of atmospheric condensation processes rightfully belongs to my able associates, particularly to Messrs. William H. Radford and Alan C. Bemis. I am certain that this award will spur us forward to greater efforts and I can only hope that our results will justify, to some extent, the honor which you have seen fit to confer on me tonight. In the future we plan to investigate the physical processes which lead to the formation of precipitation in the atmosphere in the hope that this knowledge will lead to further improvements in the science of weather forecasting.

Honorary Membership in the Institute

Conferred by the President, on behalf of the Council of the Institute upon:

Griffith Brewer, President, The Royal Aeronautical Society of Great Britain.

Lieutenant General Delos C. Emmons, Commanding General, GHQ Air Force, U.S. Army.

Major General George H. Brett, Acting Chief of the Air Corps, War Department.

Hon. Harllee Branch, Chairman, Civil Aeronautics Board.

Honorary Fellowship and Fellowship in the Institute

Pursuant to the vote of the Fellows and Honorary Fellows of the Institute in 1940, the grade of Honorary Fellow, for pre-eminence in aeronautics, was conferred by the President upon Dr. George W. Lewis.

The grade of Fellow, for distinction in aeronautics and notable and valuable contributions in one of the aeronautical sciences or aeronautical engineering, was conferred by the President upon the fellowing ten members elected to this grade in 1940 by the Fellows and Honorary Fellows of the Institute: Allan Chilton, Charles H. Colvin, Smith J. De France, Melvin N. Gough, S. D. Heron, Major Paul H. Kemmer, Paul Kollsman, George A. Page, Jr., F. W. Reichelderfer and Igor Alexis Sikorsky.

Announcement of Gifts

Lester D. Gardner, President of the Aeronautical Archives and Executive Vice-President of the Institute of the Aeronautical Sciences, acknowledged gifts that had been made to the Institute during the past year and presented certificates of Benefactor Membership to donors.

MR. GARDNER: It is my pleasant privilege tonight to express the appreciation of the Institute to those who have contributed to its various services.

A year ago we started the Aeronautical Archives. It was only a hope until Mr. Burden placed his great aeronautical library in our custody, at once making the Archives one of the best sources of reference in this country. We all feel that he has rendered a great service by making this collection of about 15,000 books available to the public.

About the same time the usefulness of the Archives was greatly enlarged by a gift of $50,000 from Paul Kollsman and the Square D Company to establish a lending library. Over eight hundred persons from all over the country are using the library and we have loaned by mail over five hundred books in two or three months. Mr. Kollsman is here tonight and I wish to thank him again for his great generosity and present him with his certificate of Benefactor Membership. I wish Mr. Magin of the Square D Company had not been prevented from being with us tonight. I hope Mr. Kollsman will let him know that our gratitude is continuous.

Grover Loening is presenting his splendid collection of books and papers to the Archives. Last week we were informed that one of the most complete collections of aeronautical material was to be placed in the Archives. The donor has been assembling it for thirty years. I am sure that you will all be pleased to know that Dr. Edward P. Warner has made this generous and valuable gift. This month C. D. Hanscom, an Associate Fellow of the Institute who has also been collecting technical aeronautical books for over twenty-five years, let us select about two hundred and fifty books on aeronautical engineering from his library and presented them to the Archives.

You have possibly wondered why the balconies here are hung with prints and aeronautical music. It is part of a secret which we have kept until we could make the first public announcement at this dinner.

We are concerned mainly with the aeronautical sciences. There is, however, a remarkable field of art in aeronautics with which most of us are less familiar. We have known of its existence but few have had the time or the means to explore its possibilities. As with so many other of the finer things of life, it remained for a lady, here in New York, to become interested in every possible phase of aeronautical art. For over twenty years she searched the art shops of Europe and the United States for all kinds of prints, etchings, engravings, posters, photographs, music, medallions, book plates, trade cards, and so on.

Last year, Harry Guggenheim loaned the Archives his fine collection of prints and engravings and we asked this lady if she would help us catalogue them. She came to the Archives every day for several weeks and became better acquainted with its pur-

poses. You can imagine my surprise when one morning she came to my office and said: "For many years I thought about what I would do with my aeronautical collection and as there seemed to be no appropriate place for it I gave it to my son. If these Archives had been in existence then, I would have given it to you." And then to my amazement she continued: "I have talked the matter over with my son and he agrees with me that they should be placed where they would be available to the public. If the Archives would like them I will be glad to present them as an outright gift."

This meant that the Aeronautical Archives of the Institute could add to the scope of its services and have available one of the greatest collections of historical aeronautical art in the world.

The samples you see here are not a hundredth part of the entire collection. They were not selected for their rarity or artistic value but only to be decorative. The collection is amazing in extent. For instance, who ever knew that there were over a thousand aeronautical musical compositions? There are and we have that collection which is unique in the world. There are more than a hundred aeronautical book plates and hundreds of trade cards. Of course, the most valuable part of the collection is the prints. No print was too rare for her to acquire. There are thousands of items in the collection. I spent six hours one day looking at them and had seen only a part.

The destruction of such artistic collections during the present war will make it increasingly difficult, if not impossible, to assemble again such treasures as have been secured here and abroad during the past twenty years. This gift will make it possible to follow pictorially the history of the development of aeronautics from the days of Leonardo da Vinci.

It will surprise many to learn that in both art and literature, aeronautics can antedate as well as surpass almost any other branch of science. This collection, with its prints by famous artists, will add greatly to the advancement of aeronautics by providing original sources of material for the study of aeronautical scientific development.

Mrs. Bella C. Landauer, donor of art collection to the Aeronautical Archives.

Our benefactor is here tonight surrounded by the other charming ladies up in the balcony. I wish to thank Mrs. Bella C. Landauer for her great generosity. I also wish to thank her son, William Landauer, for his part in making this gift possible and ask him to please come forward and receive the certificate of Benefactor Member of the Institute for his mother.

Last year the Institute was able with the assistance of generous friends to take its place as a storehouse of aeronautical information. Let us hope that 1941 will be as noteworthy.

Address by the Guest of Honor

Griffith Brewer, President of the Royal Aeronautical Society of Great Britain, was introduced by the President of the Institute as the Guest of Honor and principal speaker for the evening.

MAJOR DOOLITTLE: We are fortunate, as well as honored, this year to have with us as our guest a gentleman who holds a unique position in the world of aeronautics. As President of the oldest aeronautical society in the world as well as one of its Honorary Fellows, he would be welcome, since the Institute is in many ways a descendant in spirit, if not in fact, of this famous organization. But Mr. Griffith Brewer is more than just the head of another scientific society. In his own right he can be regarded as one of the most distinguished personages in aeronautics. His career in aviation spans more years than that of any man now living and probably of any man in aeronautical history. He first took to the air in 1891, fifty years ago this coming May. Since then, his interest and activity has been continuous. He was the first Englishman to fly as a passenger with Wilbur Wright. He learned to fly in Dayton in 1914 and has flown regularly up to last year when civilian flying was stopped in England because of the war.

We thought that you would like to hear his reminiscences and have him tell just how the advance of aeronautics has impressed him as viewed from the eminence of a half century.

"Fifty Years of Aeronautical Experience"

MR. BREWER: I will not weary you with a history of aeronautics, but will draw from my recollection a number of disconnected views, more like an old lantern show than like a continuous modern talkie film.

You may well ask, "Why did you want to go up in a balloon?" The answer is simple—that was the only way at that time to go up in the air. Flying inventors had promised so much and accomplished so little, no one could tell whether they would ever fly; so in 1891 it seemed to me that the practical thing to do was to use the only means then known of getting up in the air. The balloon did not completely satisfy my ambition because you could only go where you were taken by the wind, but to wait for the success of experiments which had been going on unsuccessfully for a century did not satisfy my desire to look down from the air, when it was within my grasp by using the century-old gas bag.

For seventeen years the balloon bridged the gap between theory and practice, and then Wilbur and Orville Wright came to Europe, and all those air-minded balloonists were immediately converted to the new art. It was then that the Aeronautical Society came into its own. Its members held up their heads with greater confidence, and the strength of the Society has progressed by leaps and bounds ever since.

It is that old organization, the Royal Aeronautical Society, founded in 1866, that I have the honor to represent tonight. We are proud to know that the Institute of the Aeronautical Sciences has found in our organization many features on which to mould your younger and perhaps more vigorous organization. Both bodies may be regarded as the Universities of Aeronautics, for, as Carlyle once said, "The true University of these days is a

collection of books," and these two aeronautical organizations now possess libraries and archives on the subject of aeronautics which are without their equal elsewhere.

Fifty years ago there were no Aero Clubs to help one to go up in the air. The only way to go up was to get a professional aeronaut to take you in the car of his balloon. Balloons went up at exhibitions and formed the chief attraction in the afternoon. "What time does the balloon go up?" was the general question of the crowd at the pay entrance.

In May, 1891, I booked my seat with C. G. Spencer and Sons, for the first ascent of the season at the Naval Exhibition at Chelsea. It was a windy day with low clouds. The car of the balloon, filled with bags of sand and held by the ground crew, was rolling about in a manner to delight the crowd. The aeronaut told his three passengers to get into the car, so we climbed in and were rolled about with the ballast. Bags of sand were then removed until the balloon was found to lift, and then, with a further release of some more bags, taken out to insure a good lift, the order to let go was given and the balloon literally shot up into the air. I would remind you that we were part of the show, and nothing impressed the crowd so much as a quick ascent. So, from a spectacular point of view, that ascent gave the people their money's worth. In less than a minute, the balloon entered the clouds and left the crowd wondering what would become of us. The passengers were all young men who enjoyed the adventure, and the novelty of being in the clouds was followed by the surprise and delight of coming out on the top side into brilliant sunshine.

A few days after this first adventure, I went to see Spencer and explained that I wanted to learn ballooning but could not afford to pay £5 each time for my seat. I proposed that I should go to the Exhibition every Saturday and help in the preparation of the balloon for the ascent and then, at the last moment, if there were no passengers, I would get into the car with him and pay £1 for my passage. To this he agreed and, for the remainder of the season, I learned all the work of laying out and inflating the balloon. Whenever the day was too rough to tempt passengers, I would get into the car and share the afternoon's adventure with Spencer. By the end of the summer of 1891 I had become sufficiently skilled to take charge of a balloon.

The only instruments used in balloons fifty years ago were an aneroid barometer, to indicate the altitude, and pieces of thin paper which, when thrown from the car, showed whether the balloon was rising or falling. If the paper fell, we knew we were rising, and if it shot up into the air, we knew we were falling. The paper could be regarded as stationary points from which to compare the movements of the balloon.

In addition to the money paid to the aeronaut by the exhibition and the passenger money, the aeronaut made up a scanty living by taking up a quantity of leaflets advertising "Greenless Whiskey." Of course, we were not interested in the whiskey, but we were interested in observing the speed of descent of fluttering leaflets. We gauged their speed of fall at 30 feet per minute. We found that if we threw them from an altitude of 5000 feet and landed two and a half hours later, we should land amongst them.

This simple method of estimating the landing place of leaflets thrown from aircraft might have been useful when, more than forty years later, leaflets thrown from British aircraft over Berlin came down outside Germany. Had the leaflets been thrown at 10,000 feet over France in a fifty mile an hour westerly wind, they would have landed in Germany, 500 to 800 miles away—the distance varying with the thickness of the leaflets.

For the next ten years the science of ballooning did not change. There was no private ballooning, nor were there any privately owned balloons. The only amateurs who went up in the air did so either by hiring a balloon piloted by a professional aeronaut or by paying for their seats as passengers in balloons which went up as a show. It was not until 1902 that ballooning as a sport began with the formation of the Aero-Club de France, which was followed shortly afterward by the founding of the Aero Club of Great Britain. The clubs bought balloons and some of the members had private balloons made for them. This introduced a healthy competition.

The rip panel was introduced from France and statoscopes took the place of throwing out paper for seeing whether the balloon was rising or falling. Balloons were made spherical instead of pearshaped. Members of the Aero Clubs began to take up balloons without the help of professionals.

In 1906, I was aide to Frank Butler in the first Gordon Bennett Balloon Race from Paris. We landed at Blonville rather than face the Channel crossing, which is about a hundred miles wide at that point. I am pleased to see the winner of that race here tonight, the same Colonel Lahm whom you have heard this evening. He had greater confidence than we and went out over the Channel and right up the length of England to Yorkshire, thereby winning the first Gordon Bennett Balloon Race. This American success brought the Cup to America, where I followed it to St. Louis in 1907, when Claude Brabazon was my aide. We had an exciting time in America, but we came in at the wrong end in the race, landing in Washington County, Ohio.

In 1908, Wilbur and Orville Wright changed our easy going ballooning days into the more strenuous activity of aeroplane flying. Up to that time, the Aeronautical Society had for forty years been discussing the science of flying without making any progress. The balloonists had been racing their balloons and smiling with skeptical indulgence on the flying men who tried to fly but couldn't. But while we had been racing and discussing, Wilbur and Orville Wright had been compiling tables of air pressures on aerofoils, making gliders based on their original research, and then risking their necks until, on the 17th of December, 1903, they made those first flights which were destined to shake the very foundations of modern civilization.

The British Government knew o the success of the Wrights and very wisely did not encourage it. The United States Government seemed equally reticent, although it had spent a large amount of money on scientific aeronautical experiments. The public, too, missed its great opportunity of recognizing the triumph of the two sons of Bishop Wright who had succeeded when orthodox science had failed.

French sportsmen, many of whom had tasted the joys of ballooning, investigated the Wright experiments and then, when they had learned part of their methods, began experiments themselves and made crude imperfect copies of the Wright machine. They succeeded in making hops and heralded each hop as a new triumph. Then Wilbur Wright came to France and flew in the autumn of 1908. He flew figures of eight at the height of the tree tops. He carried passengers from several countries, four of whom were English. There was no question, now, of whether flying was possible. All Europe heralded the entry of the flying age.

I heard of Wilbur Wright flying at Le Mans, and wrote to ask him whether I could come and see him. He replied, saying he would be pleased for me to do so. Charles Rolls asked me why I was going to France. I replied "Don't tell any one, but I am going to see Wilbur Wright." He replied, "Don't tell any one, but I have just returned from seeing him fly."

I went to Le Mans. When I arrived at the Champs d'Auvours I found the machine was out on the field and Wilbur was tuning it up. There was quite a crowd buzzing round Wilbur at his work. As you know, a crowd of that kind is very disconcerting, so I had some compunction in adding to it. Instead of going out in the field to the machine, I sat on the ground by the shed and smoked my pipe. A mechanic came from the machine over to the shed to fetch a spanner, so I gave him my card to give to Wilbur Wright. When he returned, I saw Wilbur look at the card and he nodded across to me and then went on with his work.

Time went on. There was no flight. Ultimately, the ma-

chine was wheeled back to the shed. The crowd dispersed, going back to Le Mans, and I began to think I was forgotten. Still sitting with my back to the shed, the machine and Wilbur both inside, I wondered whether I should sit out there indefinitely. Then out came Wilbur Wright and said, "Now, Mr. Brewer, we'll go and have some dinner."

We went across to Madam Pollet's Inn and had a very nice simple dinner. We talked of all things American, and I did not bother him with aviation. That was probably his first rest from the subject of flying since he had left his home in Ohio many weeks before.

On a later visit, Wilbur invited me to fly with him. I had all the thrills of a first flight but with a genius greater than any I had ever known.

After my first flight with Wilbur Wright, I kept in touch with aviation by paying annual visits of one or two weeks to the Wrights, with whom I was privileged to enjoy the warmest friendship. In 1914, I made a visit of several months instead of my usual two or three weeks. I took advantage of this long stay to learn to fly at the original Wright School at Dayton. Before securing my pilot's license, the World War began. Cables came to me from home urging my immediate return. I felt, however, that flying was of more importance than any war, so I continued flying in the early morn and in the evening, and sleeping in the airplane shed, until that unforgettable day when I flew my solo tests before Orville Wright and his sister Katherine.

On my return to England, I was considered too old to be an active airplane pilot but my ballooning experience was used for instruction and experiments in kite ballooning at Roehampton. For three years I lectured to probation officers on the theory of ballooning and, in my capacity as Honorary Adviser to the Airship and Kite Ballooning Services, I carried out experiments with kite balloons in order to make them safe if the cable broke. This resulted in a device, which became known as the "Brewer Rip," enabling lighter cables to be used, and higher observation flights to be made with safety by eliminating the danger to the pilot attendant on breaking away.

In 1929, I resumed active flying by taking instruction at Hanworth in flying a "Moth." I rather feared that at 62 I might be too old to learn the new controls, but after 80 hours' dual, under nine different instructors, Flight Lieutenant Ralph Preston had the nerve to send me solo. Again, I experienced the thrill which comes but once to most flyers—of being alone with the "joy stick," knowing that there is no master pilot to pull you out of difficulties.

I bought a Moth, and flew it continuously for the next nine years. Every Saturday, I went to Hanworth and regained my youth. A part of my routine consisted of making three loops. When Orville Wright heard of this, he remonstrated with me, and I promised to give up looping. Perhaps my willingness was more ready because, on two occasions, I had found after looping that I had forgotten to fasten my belt. Fortunately, the loops were good ones. During the nine years' flying, I made over a thousand flights—all solo except two.

I have been referred to, on some occasions, as "the first Englishman to fly." I think the description should be the "first Englishman to go up in an aeroplane," because the first Englishman to pilot an aeroplane was J. T. C. Moore-Brabazon when he took his pilot's license a year or so after Wilbur Wright took me up as a passenger. He is, in the active sense, the first Englishman to fly. Moore-Brabazon, as you may know, was a former President of the Royal Aeronautical Society and is today a member of the British Government and Minister of Transport. We flew balloons together and against each other and have always been the warmest friends.

During this period, I had the enjoyable experience of crossing the Atlantic in the "Hindenburg" and making a trip from Hanworth to Friedrichshafen in the "Graf Zeppelin." I also flew an autogiro.

In concluding these reminiscences, I wish to say a few words as President of the Royal Aeronautical Society. Our Society was one of the first to acclaim the achievements of the Wright Brothers and we have refreshed our memories each year by holding the Wilbur Wright Memorial Lecture.

Six years before the Institute was founded, we were asked to give a complete picture of the organization and work of our Society, as several of our American Fellows were making plans to form a similar society in the United States. When the Institute was started nine years ago, we were gratified to hear that the Founders felt that some of our purposes could be followed in this country. Since then, the cordial relationship has become ever closer, because we have had such a pleasant interchange of visits by our officers and members.

We do things more slowly in England than you do here. It has amazed me on successive visits to New York to watch the progress the Institute is making. The distinguished attendance at this dinner is another indication of the prestige of your membership. May your success continue to advance the aeronautical sciences.

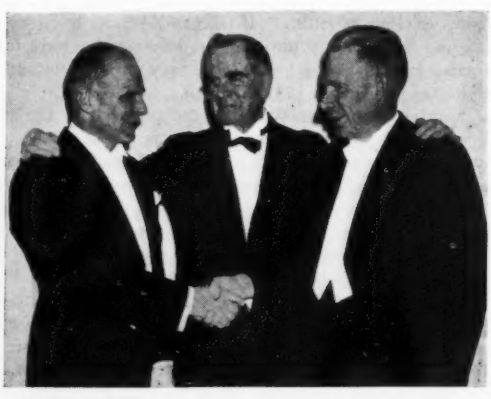
I have just received a cable from the Secretary of the Royal Aeronautical Society as follows: "The Council wish you to convey to the Institute how much they appreciate the honor of choosing our President as the Guest of Honor of their Honors Meeting and to wish them a highly successful evening. They look forward to the time when they will be able to reciprocate the courtesies paid to you, Mr. President. (Signed) Pritchard, Secretary."

Let us use a symbol of our cooperation and friendship, which should keep us always close together. I propose this pledge in the form of a toast to "Wings Across the Seas."

Induction of President of the Institute for 1941

Frank W. Caldwell, Director of Research of the United Aircraft Corporation, was inducted into the office of President of the Institute for 1941, by the Retiring President.

MAJOR DOOLITTLE: I have enjoyed being your President. I am grateful for the support that the other Officers, the Council and the members have given. I was particularly impressed, when Major Gardner and I visited twenty-five Student Branches last year, by the great interest in the Institute shown by our Student Members.



Left to right: Major James H. Doolittle, retiring President of the I.Ae.S., Griffith Brewer, President of the Royal Aeronautical Society, and Frank W. Caldwell, President of the I.Ae.S. for 1941 (*Wide World photo*).

As President for this year, a man has been elected whose aeronautical career since 1912 has been one of great success. He is responsible for much of the great progress that has been made in military and civil aeronautics, particularly through his research in the field of propellers. He was the recipient of the Collier Trophy in 1933 and in 1936 received the Sylvanus Albert Reed Award. As Director of Research of the great United Aircraft group, he will play an important part in our defense program. I congratulate the Institute and now turn over the reins to my old friend, Frank Caldwell.

MR. CALDWELL: I am most appreciative of the honor of being elected President of the Institute.

I feel a great deal of humility in attempting to carry on the splendid work of my eight predecessors. Under their leadership the Institute has grown from a small nucleus to a great organization with international importance.

Indeed the Institute may be said to have reached a certain maturity as far as size is concerned so that our objective may now be aimed at greater usefulness to the membership, to the industry and to the country.

We are living through a period of great changes in the world order on which the art of flying is exerting a profound influence. It seems clear that this influence is going to increase whether in war or in peace.

More than any other group in the world the membership of our Institute may be said to have created the airplane and made it practical. This goes all the way from Orville Wright on down the line. It is equally true that our membership has the opportunity to develop the airplane into an instrument of the highest value to our great country. Let us do it.

Institute of the Aeronautical Sciences Ninth Annual Meeting

THE Technical Sessions of the Ninth Annual Meeting of the Institute were held at Columbia University, New York City, on Wednesday, Thursday and Friday, January 29–31, 1941. Fifty-three papers and demonstrations were presented at sessions covering ten different fields of the aeronautical sciences, the titles of which have been published in the January, 1941, issue of the Journal and in the final program given out at the Meeting. Preprints of some of the papers presented were made available by the authors for distribution to persons attending the Meeting. All of these preprints have now been distributed, but many of the papers given at the Meeting are being published in this and succeeding issues of the Journal. A review of the technical sessions will be found in the Aeronautical Review Section of this issue.

Over 750 persons attended the various morning, afternoon and evening sessions. The innovation of evening sessions at the Annual Meeting was well received as indicated by the good attendance at the two such sessions held this year. Members and guests evinced great interest in the exhibits of apparatus, instruments and materials displayed by several firms in the Registration Room and in The Paul Kollsman Library's exhibit of recent aeronautical books.

The minutes of the Annual Business Meeting held on January 29th are given below.

Minutes of the Ninth Annual Business Meeting of Members

The Ninth Annual Business Meeting of Members of the Institute of the Aeronautical Sciences, Inc., was held in the Pupin Physics Laboratories Building of Columbia University, New York, at 5:00 p.m. on Wednesday, January 29, 1941. Lester D. Gardner, Executive Vice-President of the Institute, presided in the absence of the President. C. E. Sinclair acted as secretary of the meeting.

H. J. E. Reid, E. E. Aldrin and Ralph Upson, tellers, reported that they had received and counted 521 valid proxies for voting at the Annual Business Meeting—a quorum.

Dr. J. C. Hunsaker, on behalf of the Nominating Committee, placed in nomination the following members for election to vacancies on the Council: Leroy R. Grumman, to serve for a term of two years; W. Wallace Kellett, Bruce G. Leighton, R. D. MacCart and Arthur Nutt to serve for terms of three years each. On motion duly made, seconded and carried, they were unanimously elected. The following were duly nominated and unanimously elected to serve on the Advisory Board for the year 1941: John D. Akerman, Lawrence D. Bell, Vincent Bendix, George H. Brett, Lyman J. Briggs, Jack Frye, J. H. Kindelberger, F. K. Kirsten, A. L. Klein, Alexander Klemin, Paul Kollsman, S. Paul Johnston, Harold F. Pitcairn, A. E. Raymond, F. W. Reichelderfer, M. J. Thompson, J. H. Towers, J. T. Trippe, A. D. Tuttle, E. P. Warner.

Charles H. Colvin placed in nomination the following Past-Presidents of the Institute to serve as the Nominating Committee for 1941; J. H. Doolittle, J. C. Hunsaker, G. W. Lewis, Clark B. Millikan and T. P. Wright. On motion duly made, seconded and carried, they were elected.

The Annual Reports of the President, the Treasurer and the Secretary were read and approved as follows:

The President's Annual Report

This year, the Institute begins its ninth year of service to the aeronautical profession. It has every reason to feel that in that short period of its history, it has laid a firm foundation on which further upbuilding can be done with assurance and confidence.

The members of the Institute are practically all engaged in work related to the National Defense program. To organize special committees to supplement this work has not been con-

Philip G. Johnson
Vice-President

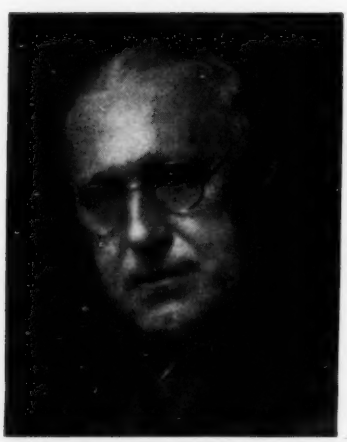
Frank W. Caldwell
President

Hall L. Hibbard
Vice-President

William A. M. Burden
Vice-President

Officers
of the
Institute
for
1941

Charles H. Colvin
Vice-President



Lester D. Gardner
Executive Vice-President

Grover Loening
Treasurer

C. E. Sinclair
Secretary

sidered advisable, as it would probably result in duplication of effort. The Institute is cooperating with governmental agencies in every possible way and will expand this service as requested.

Aeronautical Archives. Last year will always be notable in the history of the Institute. The Aeronautical Archives were opened for the use of members and the public. The Burden Library was moved to the Institute headquarters and is used every day by those seeking aeronautical information. A reading room is now open which permits the Institute to make available its great resources of aeronautical books and magazines.

In addition to the reference library, the Institute received a gift of $50,000 to establish a lending library which permits members and others to borrow books and receive them by mail. It also made it possible to start the "Aeronautical Review." Paul Kollsman and the Square D Company of Detroit were the donors of this fund and to them the Institute will always be grateful.

The scope of the Aeronautical Archives was also greatly expanded by a gift of aeronautical art by Mrs. Bella C. Landauer of New York. For twenty years she has collected prints, music, posters, photographs, book plates, trade cards and other aeronautica. It is considered one of the most comprehensive, rare and valuable collections in the world. It covers the early history of aeronautics and has English, French, German and Japanese prints as well as an unsurpassed group of American etchings and engravings. The Council has elected Mrs. Landauer a Benefactor Member of the Institute and believes that her contribution to the Institute will enable the Archives to take front rank in aeronautical art as well as the sciences.

Mr. Harry Guggenheim has also placed his fine collection of aeronautical prints in the custody of the Archives. This supplements the Landauer collection and still further adds to the extent of the aeronautical art available in the Archives. Many others have made valuable gifts during the year. The National Aeronautic Association has loaned the Institute its library and many interesting trophies and relics. Others have promised gifts which will further extend the usefulness of this important service of the Institute.

Financial. The Treasurer's report will show that the Institute doubled its assets last year and operated within its income.

Membership. A steady growth in membership in a scientific society is preferable to any forced gains. The Secretary's report will show that the Institute has made satisfactory increases during 1940.

Journal of the Aeronautical Sciences. Under the able editorial direction of Dr. J. C. Hunsaker the Journal continues to maintain its high standard of technical papers.

The Aeronautical Review. This magazine, published as a section of the Journal and also as a separate edition, was started with the aid of The Paul Kollsman Library Fund to give engineers and others a monthly summary of the more important aeronautical books and articles from magazines and house organs. It is too early to determine whether or not it will be able to fulfill the requirements of an over-worked aeronautical profession, but the comments thus far received have been favorable.

The Aeronautical Reader's Guide. This quarterly is intended to be a current classified catalogue of The Paul Kollsman Library and supplementary lists of aeronautical books in specialized fields. It is performing a useful service to those who wish to secure the titles of the more important and recent books in the aeronautical and allied fields.

Dues. The increase in dues which was made last year has been accepted by the membership as part of the general advance in costs necessary to maintain the Journal and other services of the Institute.

Branches. Your President and Executive Vice-President last year observed personally the fine spirit with which Student Members and Affiliates were maintaining their work.

Awards. Two new awards were established by the Institute last year. The John Jeffries Award, honoring the memory of Dr. John Jeffries, the American physician who made the first aerial voyage across the English Channel with the French balloonist Blanchard in 1785 and made the earliest recorded scientific observations from the air, gives recognition to the importance of aviation medicine by providing a certificate of award "for outstanding contributions to the advancement of aeronautics through medical research." The Robert M. Losey Award is in honor of the late Captain Losey, a member of the Institute and a meteorological officer of the U.S. Army Air Corps, who was killed in Norway last year while on duty as an observer for the United States Government. This award is to be given annually "in recognition of outstanding contributions to the science of meteorology as applied to aeronautics." As these awards are not endowed, they carry no honorarium, but only a certificate. They have both been awarded for the first time for the year 1940.

Annual awards for Student Members were established last year. The senior student in each Branch who attains the highest scholastic standing and also the student who presents the best paper before a meeting of his Branch during the year each receive a certificate of award and prepayment of Technical Membership dues for two years.

Student Pilot Contest. Last year the Institute supervised the Shell Intercollegiate Aviation Scholarships and Awards Contest in which hundreds of college students in the Civilian Pilot Training Program participated. A luncheon was held in Washington in August at which the final awards were made.

Meetings. Owing to the requirements of governmental departments regarding the presentation of technical material, the Institute is using extreme caution in the conduct of its meetings. Its Annual Meetings in New York and on the Pacific Coast will maintain the high standards adhered to previously, but with due regard to prevailing conditions.

Aeronautical Index. The Work Projects Administration continued to provide workers to expand the bibliographical and biographical files and several supplements to the fifty bibliographies which have been published have been issued which have brought them up to date. The Index and the library supplement one another and enable readers to locate any information they wish to find quickly. Experienced librarians are available to assist visitors.

Research Service. Hundreds of requests for technical information are received by the Institute from members, writers and others. Much of this service can be given without charge but where it requires lengthy investigation, a staff of technical experts and translators is available that can do extended research.

Headquarters Activities. With the addition of the libraries and expanded indexes, it was necessary for the Institute to move to larger offices in the RCA Building. Members who have visited the Archives have seen the invaluable collections which the Institute must protect. As these are expanded, the requirements for even larger quarters will become a problem which will have to be considered within the next few years. The management of the Institute is under the direction of a competent staff. The Executive Vice-President has organized each of the Institute's activities so that he is now able to give more of his attention to the financial problems of the expanding services of the Aeronautical Archives. He should be relieved as much as possible of the burdensome details so as to devote more of his time to the placing of the Institute on a permanently sound financial basis.

It has been my privilege to be your President during a year of noteworthy growth and I am sure that I express the appreciation of the membership for the loyal and efficient work of the Institute's Staff. The Council and Officers who will direct the policy of the Institute for the coming year will find that the foundation which has been laid during the past eight years is sound and that they will only have to continue the traditions and precedents which have been established to bring ever increasing prestige to our society.

JAMES H. DOOLITTLE

For the Fiscal Year October 1, 1939, to September 30, 1940

Consolidated Balance Sheet

ASSETS

General Fund Assets		
Cash on Hand and in Bank	$ 4,877.40	
Deposits and Advances	570.00	
Accounts Receivable	295.35	
The Benefactor Membership Fund:		
U.S. Treasury Bonds at Par Value (Market Value $13,072.50)	12,000.00	
Office Furniture & Equipment	$10,290.94	
Less: Reserve for Depreciation	6,422.73	3,868.21
Prepaid Expenses	962.80	
Library—Books, Prints, Models, Pictures, etc.	1.00	
Aeronautical Index	1.00	
Total General Funds		$22,575.76
Investment of Restricted Funds		
The S. A. Reed Fund:		
U.S. Treasury Bond at Par Value (Market Value $10,893.75)	$10,000.00	
Cash on Deposit for Award	344.61	$10,344.61
The Lawrence Sperry Fund:		
U.S. Treasury Bonds at Par Value (Market Value $5,446.87)	5,000.00	
Cash on Deposit for Award	314.33	5,314.33
The Vernon Lynch Fund:		
Melville Shoe Corporation Stock (Market Value $8,114.50)	5,004.00	
Peoples Drug Stores, Inc. Stock (Market Value $7,122.50)	5,272.50	
Uninvested Principal	58.50	
Unexpended Income	975.03	11,310.03
Paul Kollsman Library Fund:		
Unexpended Cash—separately deposited		18,450.83
Total Restricted Funds		$45,419.80
Total Assets*		$67,995.56

* Pledges for future gifts have been made by donors of:

The Lawrence Sperry Fund	$ 5,000.00	
The Paul Kollsman Library	25,000.00	$30,000.00
Unrealized appreciation on investments		7,315.12
		$37,315.12
Assets as above listed		67,995.56
		$105,310.68

LIABILITIES, FUNDS AND UNEXPENDED INCOME

General Funds		
Accounts Payable	$ 553.33	
Dues Received in Advance	3,262.50	
Prepaid Reprints	40.28	
Deferred Income:		
Unearned Corporate Member Dues	$ 8,693.00	
Unearned Subscriptions	1,695.00	10,388.00
Unexpended Income:		
Balance October 1, 1940	7,590.06	
Adjustment of Accumulated Depreciation	1,839.10	
Adjusted Balance	5,750.96	
Unexpended Income—Sept. 30, 1940	2,580.69	
Balance, September 30, 1940		8,331.65
Total General Funds		$22,575.76
Restricted Funds		
The S. A. Reed Fund:		
Principal	$10,000.00	
Unexpended Income	344.61	$10,344.61
The Lawrence Sperry Fund:		
Principal	5,000.00	
Unexpended Income	314.33	5,314.33
The Vernon Lynch Fund:		
Principal	10,335.00	
Unexpended Income	975.03	11,310.03
The Paul Kollsman Library Fund:		
Principal and Unexpended Income		18,450.83
Total Restricted Funds		$45,419.80
Total Liabilities, Funds and Unexpended Income		$67,995.56

Statement of Income and Expenses

INCOME

Dues and Subscriptions	$23,701.72	
Interest Earned—Benefactor Membership Bonds	198.92	
Emblems—Net Proceeds from Sales	389.36	
Entrance Fees	950.00	
Miscellaneous	278.00	$25,518.00
Net Income from Journal Publication (see detail below)		2,405.60
Total Income		$27,923.60

EXPENSE

Administration, Clerical and Accounting	$10,953.62	
Certificates of Membership	330.76	
Electricity, Telephone and Telegraph	481.72	
Office Supplies, Stationery and Printing	980.53	
Postage	670.26	
Travel and Guest Reception	738.30	
Meetings—Expense	$ 4,684.57	
Less—Income	4,039.22	645.35
Rent	995.46	
Miscellaneous	323.37	
Depreciation	518.94	
Uncollectable	213.00	
	$16,851.31	
Aeronautical Archives Maintenance	8,491.60	
Total Expense		$25,342.91
Net Unexpended Income for the Year Ended September 30, 1940		$ 2,580.69

Detail of Journal Income and Expense Journal Publication

INCOME

Corporate Member Dues	$29,746.44	
Reprints	64.81	
Total Income		$29,811.25

EXPENSE

Administration, Clerical and Accounting	$10,953.63	
Rent	995.46	
Engraving, Postage and Printing	12,521.11	
Electricity, Telephone and Telegraph	481.72	
Office Supplies, Stationery and Printing	980.53	
Travel, Guest Reception and Miscellaneous	954.26	
Depreciation	518.94	
Total Expense		$27,405.65
Corporate Member Dues Net to Institute Income		$ 2,405.60

The Treasurer's Annual Report

The statement which is submitted with this report indicates the sound financial condition of the Institute.

The assets have increased from $46,149.64 to $67,995.56 but, including gifts promised and unrealized appreciation on investments, this amounts to $105,310.68. The assets were almost doubled by the generous gift of Paul Kollsman and the Square D Company.

Every investment of the Institute's individual funds shows that the market price is higher than when they were received, a remarkable tribute to the conservative financial policy by the Council.

The liabilities of the Institute to others is negligible.

The expenditures of the Institute have been kept within its income so that $2,580.69 was added to surplus last year.

It should be noted that the Aeronautical Index, the library, collections of prints, models and trophies are carried on the books at $1.00 although they could not be replaced for several hundred thousand dollars. The office furniture and equipment has been depreciated from a cost of $10,290.94 to $3,868.21.

The books have been audited by public accountants and they report that the accounts are kept in accordance with good accounting practice and the financial statement submitted herewith correctly reflect the financial condition of the Institute.

L. R. Grumman

The Secretary's Annual Report

The past year has seen an increased interest in and attendance at meetings of the Institute, not only at the technical sessions of the last Annual Meeting, the Honors Night Dinner and the Wright Brothers Lecture held in New York, but also at the Annual Summer Meeting held on the West Coast and the meetings of local Sections and Student Branches.

The Institute has 34 Student Branches which, on January 1, 1941, had a total registered membership of 630 students. Other Student Branches are in process of formation. Registration of additional Student Members is still being received, the delay being due to changes made this year in the form of Student Branch organization. Student Members no longer pay dues to the national office. They can subscribe to Institute publications at half the regular rates and copies of the publications are sent without charge to the headquarters of each Student Branch.

During the past year seven mimeographed lectures, illustrated with projection slides, were prepared by the Institute and sent to all Student Branches and Sections. The Student Branches held 86 meetings, with a total attendance of approximately 4,000, at which these and original lectures were presented. The newly established Student Awards were presented to two Student Members from each Branch for the scholastic year ending June 1940.

There are six local Sections of the Institute in Philadelphia, Dayton, Notre Dame (Indiana), Seattle, San Francisco and Los Angeles. Additional Sections are being organized in St. Louis and San Diego. The Sections serve about 500 members of the Institute, in addition to affiliates, and held 15 meetings last year.

The following are the membership figures by grades:

	Jan. 1, 1940	Jan. 1, 1941
Honorary Fellows	17	18
Honorary Members	16	17
Fellows	167	175
Associate Fellows	513	570
MEMBERS	399	650
Industrial Members	...	140
Technical Members	891	1,475
Total in above grades	1,995	3,045
Student Members	828	630
Total Membership	2,823	3,675

The increase in membership during the past year was larger than ever before, both in proportion to the previous year's membership as well as in total figures. The net increase in the grades of MEMBER and Industrial Member was 391. Most of the new members admitted to these grades were recommended by present members. We believe that this method of adding to the enrollment through applicants proposed by members insures a membership constantly growing but at the same time maintaining its standards by the addition only of those who are qualified and are interested in the work of the Institute. We urge that our members continue to further the progress of their organization by proposing those of their colleagues who they believe would qualify as MEMBERS, Industrial Members or Technical Members.

The addition of 584 to last year's total of Technical Members is composed for the most part of former Student Members who have graduated and qualified as Technical Members under the special arrangements made for them. It has always been a part of the policy of the Institute to render all assistance and encouragement possible to young men in aeronautics. The larger enrollment in the membership grade set up for this purpose indicates a gratifying interest in and appreciation of the facilities offered by the Institute to young aeronautical engineers and technicians.

During the calendar year 1940 the total of 1,995 members, in the grades above that of Student Member, with which we started the year was increased by over half again to 3,045 members at the end of 1940. The registration of 630 Student Members at that time brought the total membership to 3,675. The Officers and Council feel that the addition of more than a thousand new members last year indicates a vote of confidence by the aviation men of the United States in the Institute's efforts and activities for the furtherance of the aeronautical sciences. It spurs our organization to the increased endeavors which the great recent growth of the aviation industry will require.

C. E. Sinclair

The Secretary presented the list of honors conferred by the Insitute for 1940, as follows:

The Sylvanus Albert Reed Award to Dr. Hugh L. Dryden.

The Octave Chanute Award to Howard R. Hughes.

The Lawrence Sperry Award to Dr. W. Bailey Oswald.

The John Jeffries Award to Dr. Louis H. Bauer

The Robert M. Losey Award to H. G. Houghton, Jr.

(Details on the above awards are published in the account of the Honors Night Dinner in this issue of the Journal.)

The Wright Brothers Lectureship to Dr. Sverre Petterssen, who presented the Lecture on December 17, 1940, on the subject "Recent Fog Investigations."

Honorary Membership in the Institute to Hon. Harllee Branch, Major General George H. Brett, Griffith Brewer and Lieut. General Delos C. Emmons.

Honorary Fellowship in the Institute to Dr. George W. Lewis.

Fellowship in the Institute to Allan Chilton, Charles H. Colvin, Smith J. De France, Melvin N. Gough, S. D. Heron, Major Paul H. Kemmer, Paul Kollsman, George A. Page, Jr., F. W. Reichelderfer and Igor Alexis Sikorsky.

A motion was duly made and carried that the thanks of the Institute membership be conveyed to Prof. George B. Pegram and Columbia University for again providing the excellent facilities of the University for the Annual Meeting.

The Secretary announced the officers of the Institute elected for 1941 by the Council at its meeting on November 8, 1940:

President—Frank W. Caldwell

Vice-Presidents—William A. M. Burden
Charles H. Colvin
Hall L. Hibbard
Philip G. Johnson

Executive Vice-President—Lester D. Gardner

Treasurer—Grover Loening

Secretary—C. E. Sinclair

Mr. Gardner introduced Frank W. Caldwell, the President for 1941. Mr. Caldwell expressed appreciation for his election to the presidency and the hope that the Institute under his leadership would be able to progress to as great an extent as it had in the past year of remarkable achievement.

There being no further business, the meeting adjourned.

Aircraft Plywood and Adhesives

THOMAS D. PERRY

Resinous Products & Chemical Company

Introduction

Plywood, as a structural material, has a utilization history of about fifty years. Decorative and artistic face veneers, always more or less fragile, had been reinforced by under layers of sturdy wood since the time of the Pharaohs in Egypt about 1500 B.C.

The design requirements of early aircraft, in the first decades of the present century, were the first real exploration of the strength/weight ratio advantages that have become so characteristic of well designed plywood. In fact, the term "Plywood" did not come into use until about this time. While it is made of *veneer*, the unfavorable and accumulated connotations of that word, made it desirable for the advocates of this material to establish the better and more descriptive title, *plywood*, which was particularly suited to strength factors of such a multi-layered product. Many other advantages of plywood, such as non-splitting, dimensional stability, distributed strength, cost, availability, ease of working, conservation of timber, facility for curving, bending and forming, need only be listed here, as they have been described adequately elsewhere.[5] With its many advantages in aircraft construction, there were a few limitations in plywood utilization that were recognized as serious handicaps in World War I.

Early Limitations to Plywood Utilization

One of the disadvantages that has been imputed to plywood, but quite incorrectly, was its tendency toward inflammability. It is perfectly apparent that the major hazard in flight is the gasoline fuel. If this becomes ignited, at any point, it matters little whether the plane is made of fabric, plywood, wood or metal, the results are equally disastrous. Experience has changed opinion on this point, due partly to better safeguards against fire, and it is no longer considered an unfavorable factor in the use of plywood as an aircraft material.

The other major limitation to wood and plywood construction, in this early period, was the character of the adhesives used in making the plywood as well as in assembling the wood and plywood parts. The adage of "the weakest link in the chain," was a singularly accurate analogy to the quality of the adhesive used in the plywood.

In order to get perspective and intelligently evaluate the excellent plywood adhesives of the present time, it is important to briefly outline the background of adhesives that were available at the time of World War I. At that period, *casein* (made from the curds of soured milk) and *albumin* (a dried blood product coagulated under heat) were considered the most durable adhesives for aircraft construction.[8,11] Neither would withstand even an elementary mold and fungi test, in fact, under suitable conditions, both encouraged such parasitic growths. Casein plywood, bonded cold and tested dry, gave excellent bonds, and the addition of lime, up to 15 per cent, improved its water resistance, but made it abrasive on edge tools. At best its resistance to continuous soaking and to alternate wet and dry tests was relatively low. It failed quickly in boiling water. Albumin plywood, hot pressed, possessed unusual water resistance, in fact could be soaked for many days, and would resist several cycles of wet and dry tests. It was not abrasive on tools, but it was found to deteriorate seriously with age.

Plywood Progress from 1920–30

In spite of these limitations plywood continued to be extensively used in aircraft for some years after the War,[9] but it was gradually displaced by metal. This was due, to a considerable extent, to the better cooperation between metal workers and the aircraft industry than was the case with the plywood makers. The metal advocates evidently were more research minded and more eager to develop the necessary scientific strength data than were the plywood group.

Phenol Formaldehyde Resin as a Plywood Adhesive

Soon after 1930, with the rapid growth of the plastic industry, resin adhesives began to attract the attention of the plywood industry. At first the *phenol formaldehyde* resin was the only one available and that in film form[14] on an import basis. While only a few hot presses were available, the hot-pressed resin plywood gave convincing evidence of far better durability than either casein or albumin, but its high import cost retarded the growth of the resin adhesive program.

By 1935 the demand for phenolic resin film was sufficiently urgent to justify domestic manufacture, which soon reduced the price to about half that of the imported supply, a typical American experience.[17] With this impetus, and the excellent durability characteristics that were found in Tego bonded plywood, the air-

Presented at the Organic and Synthetic Materials session, Ninth Annual Meeting, I.Ae.S., New York, January 30, 1941.

TABLE 1

Effect of Veneer Thickness on Plywood Strength

Plywood Bonded with Tego Phenolic Film at 500 lbs. with Alternate Cross Layers

Key	Veneer Thickness	Layers Used	Specific Gravity	Compression	Tension	Shear
A	solid birch	1	0.63	6,200*	10,100*	2,020*
B	1/8 in. birch	9	0.77	7,890	11,840	6,060
C	1/16 in. birch	17	0.72	7,980	13,920	6,330
D	1/48 in. birch	69	1.05	11,720	19,160	11,540
	Increases					
	D over A*	..	67%	89%	90%	470%
	D over B	..	46	49	62	90

Pressures and strength factors in pounds per square inch.
*Strength factors of solid wood and plywood not strictly comparable, but this fibre stress at the proportional limit in solid wood is the most available figure to compare with breaking stresses in plywood of this type.

craft industry began to renew its interest in plywood.[18] These improved durability factors were:

1. Complete waterproofness, adhesive insoluble, when wood decays, resin does not.
2. High resistance to bacterial growth.
3. Boil proofness, facilitating bending and curving after steaming.

The liquid phenolics, developed several years after the films, were also found to possess similar durability characteristics. This development of phenolic adhesives removed the principal objection to the use of plywood in aircraft, indicated above.

Technique of Hot Pressed Resin Bonding

The technique of bonding with film is definitely simpler than the mixing and spreading of a liquid, although both methods are practiced. The interleaving of the dimensioned film between veneers of 8 to 12 per cent moisture content is the only preparatory step required.[28] In the case of a phenolic solution the successive steps of mixing, spreading and pre-drying (to prevent steam blisters in hot pressing) are necessary steps before pressing. In either event, the assembled sheets of veneer and adhesives are subjected to simultaneous heat and pressure for an interval varying from 5 minutes for 1/16 in. to 12 minutes for 5/16 in. plywood, and 300°F. and a pressure according to the density of the wood, from 125 lbs. per sq.in. on spruce to 250 lbs. per sq.in. on birch. Resin adhesive technique requires more care and precision than was considered necessary with the older glues.

The effect of the thickness of the veneer layer on the strength characteristics of the plywood shows some interesting trends, although the test data is inadequate for other than general conclusions.[47] Table 1 gives the comparative results. The plywood samples were made of birch veneer under 500 lbs. specific pressure, somewhat higher than normal. It is to be observed that improvement is negligible between 1/8 in. and 1/16 in. veneer, but conspicuous from 1/16 in. to 1/48 in. Interpolation would suggest that 1/30 in. veneer would give excellent strength increments, but this remains to be confirmed.

While this procedure ordinarily applies to plywood made flat, it is equally practicable to preform (during the bonding operation) a wide variety of plywood shapes in pairs of heated metal dies, limited of course to such a range of shapes as will not rupture the veneer, the layers of which may be reinforced by thin cross layers or fabrics. Flat plywood, within reasonable limits, can be steamed thoroughly, formed and dried in wood or metal dies, the use of heat being optional and depending on the speed required. Bending without wood rupture can often be facilitated by placing veneer layers at 30° or 45° to the axis of curvature. A wide range of constructions are available for use in bending operations, with variations in thickness of veneers, grain directions, compressibility factors and the like.

One of the earlier difficulties in aircraft plywood was the gummed tape that was used to hold the sheets of veneer together, edge to edge. The narrow ribbons of paper weakened the plywood joint, due to the tendency of the paper to delaminate. Edge gluing equipment for veneer has recently become available, using heat reactive resins. The details of this operation are shown in Figs. 1 and 2, of the infeed and outfeed ends of the machine. The liquid resin is applied to the edges of the veneer as it enters the gang of rollers, a brief drying interval follows, and the partly dried resin is cured by heat applied through the rollers at the outfeed end of the machine. The speed of operation on such machines may be around 100 ft. per minute on thin veneers. The resulting edge joint is as strong as the veneer, and is difficult to distinguish. Such equipment is coming into quite general use in plywood factories.

High Density Plywood

The processes so far described apply to what is termed normal plywood, where the density of the wood may be somewhat increased by the addition of the resin and the slight compression (approximately 5–10 per cent) of the veneers required to bring the surfaces into intimate contact for positive bonding.

Further compression, with higher specific pressures during the bonding operation, imparts an entirely new

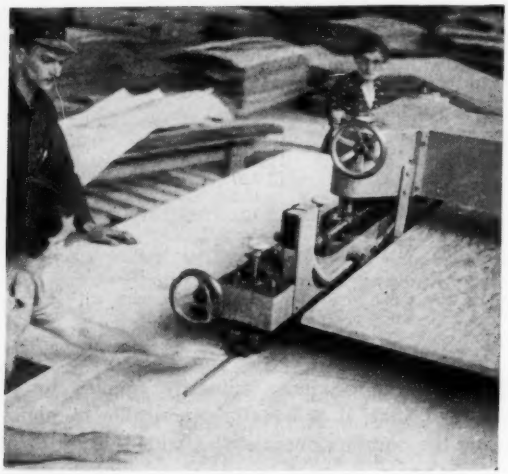


FIG. 1. Edge splicing veneer without tape. Infeed side of splicing machine. (Photo by courtesy Plycor Company, Chicago.)

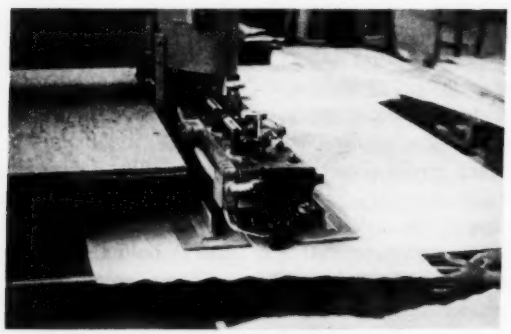


FIG. 2. Edge splicing veneer without tape. Delivery side of splicing machine, with completed edge joint. (Photo by courtesy Plycor Company, Chicago.)

range of strength properties as can be noted in Table 2 and Fig. 3.[47] The thickness of the test pieces was a full inch after compression, requiring additional sheets of veneer as the pressures were increased, as indicated in the third column of Table 2. The higher density samples were cooled thirty minutes before the removal of pressure. It is noticeable that the increases in specific gravity and strength were, in general, about double the increases in amounts of raw material required; except between 1000 and 1500 lbs. pressures, where the improvement was not significant. In other words, both the table and chart indicate, that a distinctly lower rate of increase is to be expected over 1000 lbs. The tests were made on plywood from sheets of $^1/_{48}$ in. birch veneer, with alternate layers crosslaid. Consequently the resin impregnation throughout the veneer was reasonably complete. It was discovered, somewhat unexpectedly, that poplar compressed under the same pressure, showed substantially the same specific gravity, and had approximately the same strength factors as birch.[47] It required, however, 105 sheets of $^1/_{45}$ in. poplar (as contrasted with 85 of $^1/_{48}$ in. birch) to produce a 1 in. thick sample at 1500 lbs. pressure. This would appear to indicate that wood at high densities is quite independent of original species characteristics.

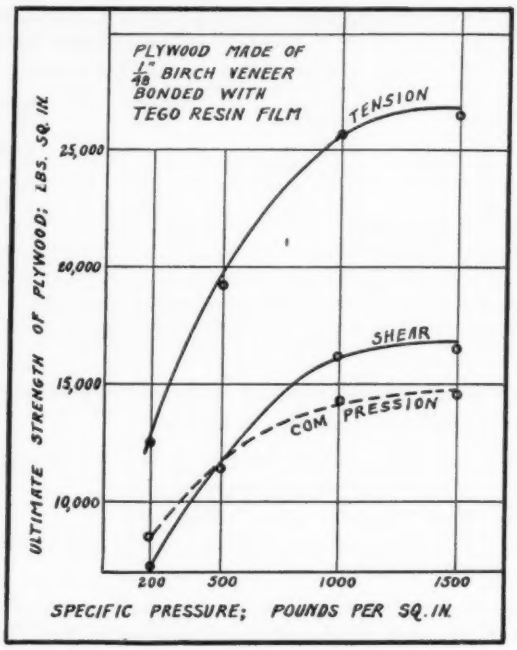


FIG. 3. Strength increases in plywood with higher specific pressures.

This high density plywood can also be made by impregnating the veneers with a liquid phenolic resin, predrying and then hot pressing as in the case of film.[24, 25, 31] While this process is considerably more complicated, it will give more complete impregnation. In general it may be said that the use of film results in *wood reinforced with resin*, with wood characteristics predominating, while the use of liquid resin produces a *plastic reinforced with wood*, more closely approaching the physical characteristics of plastics.

In both processes the plywood, when soaked, tends to expand part way back toward its original thickness, but its absorptive capacity is far less than in normal plywood.

This favorable change in plywood strength characteristics through increase of density, is somewhat analogous to the alloying and heat treatment of metals to improve their qualities. It gives to wood workers an opportunity to meet design requirements that are far beyond the range of normal wood or normal plywood.

The strength characteristics of this high density plywood have been only partly explored and published.[25, 26, 31, 42, 47] More work is in process and results will be published as fast as they are available.

TABLE 2

Effect of Increasing Bonding Pressure in Plywood

Plywood of 1/48 in. Birch Veneer, with Alternate Cross Layers, Using Single Sheets of Tego Resin Film

Key	Construction	Layers Veneer	Specific Gravity	Specific Pressure	Compression	Tension	Shear
A	Solid birch	....	0.63	.....	6,200*	10,100*	2,020*
B	Birch plywood	57	0.77	200	8,580	12,550	7,240
C	Birch plywood	69	1.05	500	11,720	19,160	11,540
D	B rch plywood	81	1.30	1,000	14,220	25,740	16,180
E	Birch plywood	85	1.35	1,500	14,410	26,760	16,130
	Increases						
	B over A*	....	22%	.....	38%	24%	258%
	E over A*	....	114	.....	132	166	700
	C over B	21%	36	.....	37	53	59
	D over B	42	69	.....	66	105	124
	E over B	49	77	.....	68	114	122
	D over C	17	24	.....	21	34	40
	E over C	23	29	.....	23	40	40
	E over D	5	4	.....	1	4	0

Pressures and strength factors in pounds per square inch.
*Strength factors of solid wood and plywood not strictly comparable, but this fibre stress at the proportional limit in solid wood is the most available figure to compare with breaking stresses in plywood of this type.

Another type of high density plywood is in the experimental stage, impregnated with lignin, that is also polymerized under simultaneous heat and pressure. Little is known of its physical characteristics, but they probably are similar to those of the resin impregnated plywood.[44]

ASSEMBLY ADHESIVES

Plywood adhesives, as they have so far been considered, are adhesives that can be applied on veneers over large areas and bonded flat or curved, by the simultaneous application of heat and pressure. The most durable plywood, from all viewpoints, is that made with phenol formaldehyde resin adhesives. Adequate machinery has been developed so that flat and moderately curved plywood can be manufactured economically.

The other major adhesive problem in the aircraft program is that of the many manual operations of putting parts together, where a suitable adhesive is admittedly superior to any type of metallic fastener, such as nails, screws and bolts, etc. In this field casein had been found the best of the glues available up to the early 1930's when the last specifications were established for the assembly of airplane parts. Its serious limitations have become increasingly evident, especially in the last year, since plywood interest has again been awakened in the airplane industry. Casein may be as strong as the wood when dry and is water resistant, but delaminates after limited soaking in cold water, and very quickly in hot water. It is abrasive for cutting tools, and is low in resistance to bacterial growths.

Resin adhesives fortunately possess the good qualities and lack the poor qualities of the caseins. Dry bonds of both adhesives, if properly applied, will break in the wood. Resins now available for airplane assembly purposes are significantly water resistant. Test samples after three months' continuous soaking still retain over half of their shear strength. In the mold and fungi test casein is practically delaminated in the 10 day test, while suitable mixtures of resin pass the 10 day bacterial exposure with a 250 pound shear test. In the matter of abrasiveness the resins are far less damaging to edge tools than the caseins.

The phenolic resins, with the quality characteristics that have been outlined for plywood, have not yet found general favor in assembly work, as their low heat reaction is definitely inadequate. Fortunately another group of resins, of the *urea formaldehyde* type, are well adapted to assembly purposes.[34, 53] With a proper catalyst, the mixtures are stable or "live" for 4 hours after mixing, and will cure at minimum room temperatures of 70°F., although the quality of the bond is improved, and its cure accelerated, by the application of heat up to 140°F. while under pressure, for a 4- to 8-hour period. These urea resins come in liquid form, which is reasonably stable for storage before catalyst is added; as well as in powder form, with catalyst incorporated, in which case the storage possibilities are definitely increased provided the powder is protected from moisture. It is often advisable to use a small amount of relatively inert extender as a "body-maker" to reduce the absorption into the more porous species of wood. Pressures for this type of cold setting resins need only be enough to bring wood surfaces into intimate contact, or to slightly compress such a soft wood as spruce.

It has been pointed out that urea resins, with a cold setting catalyst, are benefited by elevated temperatures, up to approximately 130°–140°F. One way to accomplish this is an air conditioned chamber, into which jigs, clamps and assemblies can be stored over the required bonding interval. In such cases it is important to guard against the drying of wood members, which should retain their normal moisture to preserve their resilience. The wet and dry bulb readings, neces-

TABLE 3

Equilibrium Moisture Content of Wood Products

At Various Fahrenheit Temperatures Dry and Wet Bulb Readings

Dry Bulb Temperatures Fahrenheit	Equilibrium Moisture Content of Wood											
	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%
	Wet Bulb Temperatures, Fahrenheit											
50°	34°	36°	38°	39°	40°	41°	42°	43°	44°	45°	46°	46°
55	39	41	42	43	45	46	47	48	49	50	50	51
60	43	44	46	47	49	50	51	52	53	54	55	56
65	46	48	49	51	53	54	56	57	58	59	60	60
70	50	51	53	55	57	58	60	61	63	64	64	65
75	53	55	57	59	61	63	64	66	67	68	69	70
80	56	58	60	63	65	67	69	70	72	73	74	75
85	59	63	64	66	69	71	73	75	76	77	78	79
90	..	65	68	70	73	76	78	79	81	82	83	84
95	..	69	72	75	78	80	82	84	85	87	88	89
100	..	..	76	79	82	85	87	89	90	92	93	94
105	..	..	80	83	86	89	92	94	95	96	98	99
110	..	..	84	88	91	94	96	98	100	101	103	104
115	..	..	..	92	96	99	101	103	105	106	107	109
120	..	..	..	97	100	103	106	108	110	111	112	114
125	..	..	..	102	105	108	111	113	115	116	118	119
130	..	..	..	107	110	113	116	118	120	121	123	124
135	..	..	..	111	115	118	121	123	125	127	128	129
140	..	..	..	116	120	123	126	128	130	132	133	134
145	..	..	..	121	125	128	131	133	135	137	138	139
150	..	..	..	126	130	133	136	138	140	142	143	144
155	..	..	..	131	135	139	142	144	146	147	148	150
160	..	..	..	136	140	144	147	149	151	152	154	155
165	..	..	..	141	145	149	152	154	156	158	159	160
170	..	..	..	146	151	154	157	159	161	163	164	166

Examples:

A. What air conditions are required to maintain veneer at 10% M.C. for Tego film bonding? At 90°F. dry bulb, set humidifier for 78°F. on wet bulb.

B. In an oven, where clamped cold set resin assemblies are placed overnight, if M.C. of the wood is to be kept at 12%, and oven heat is 130°F. (dry bulb); set regulator for wet bulb of 120°F.

sary to maintain an equilibrium moisture content over the required ranges are given in Table 3. It is also a useful table for air conditioning of any wood shop.

A similar type of urea resin[34] is also available for hot pressing, where temperatures of 230° to 260°F. and specific pressures of 100 lbs. sq.in. and up, can both be obtained simultaneously, as in standard flat plywood. Its use, in aircraft plywood, however, is to be discouraged, since the phenolics give a more durable bond at slightly higher temperatures, and the phenolics are boil proof, heat proof and far more resistant to continuous and intermittent soaking.

MOLDED AIRPLANES AND SUB-ASSEMBLIES

There has been much publicity on the subject of *Plastic Planes*, a somewhat inaccurate description, as the planes so far made have been molded plywood with resin adhesives and finishes, which hardly justify the use of the comprehensive term plastic plane.[50, 55] The principles involved in molding plywood are old, and the only novel features were the methods of applying the pressure as well as the unusually large size of the molded unit. The fundamental principle involved is that of using an inflated or deflated rubber bag as one of the halves of a pair of molding dies. There is not only the saving in matching up a pair of dies where the intermediate distance between halves must be very accurately determined, but in many cases the dies are wholly eliminated and, in any event, *rubber bag pressure* is of the order of fluid pressure and at substantially right angles to any surface that is under pressure. The Duramold, Timm and Vidal processes all utilize this rubber bag pressure principle.

Several of the more important applications of these rubber bag pressure principles are shown in Fig. 4. The upper sketch (Fig. 4-I) shows an early type of *vacuum bag*, used with cold setting glues, for the facing of wood core pilasters with veneers. The wood cores are accurately machined and very thin veneers are used. After the adhesive is applied, the parts are assembled and inserted in the rubber bag where the pressure is reduced to an approximate vacuum. While this pressure cannot exceed 15 lbs., the manual pressing and rubbing of the veneers against the cores, through the bag, will help to smooth out the curves. Quick-setting glues, of a tacky nature hasten this operation.

The next sketch (Fig. 4-II) indicates a method that has been used to mold half-fuselages. Here the inner mold may be made of metal or wood, and if metal, may be provided with heating units. The outer shell must be of sheet metal, substantially semi-cylindrical in shape, and firmly bolted to the base plate on which the inner mold rests. The wood parts, to be molded, may be of veneer or plywood, but must be cut to such tapers that each layer covers the preceding completely and without laps. These parts must be held in approximate locations by tacks (if a wooden mold), paper or cloth tape, steel bands or wire. A *deflated*

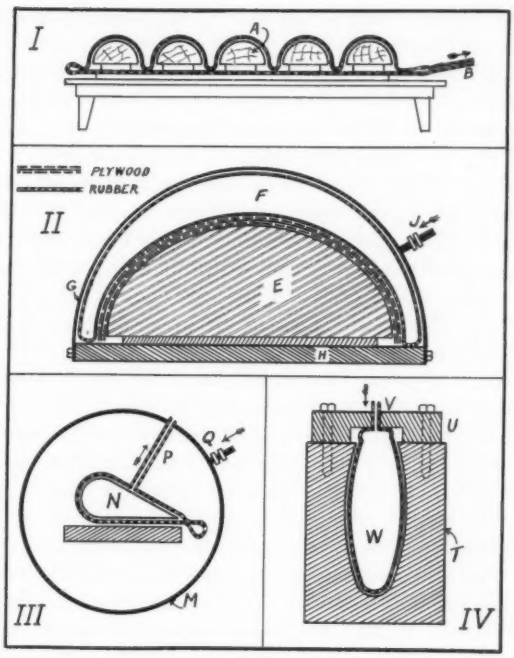


FIG. 4. Molding processes for aircraft. Typical diagrammatic sections, no scale. Using rubber bag pressures.

I *Molding with Vacuum Bags.*
- A. Solid wood pilasters to be veneer faced.
- B. Vacuum exhaust outlet.

II *Molding a Half Fuselage.*
- E. Inside mold, may be metal with steam pipes, or framed wood with slots for rings and longerons.
- F. Rubber bag, inflated with air, steam or hot water, through inlet J.
- G. Outer steel shell, bolted to base H.

III *Molding Sub Assembly Parts in Pressure Tanks.*
- M. Outer steel tank.
- N. Sub assembly, inside of rubber bag.
- P. Vent to atmosphere, or vacuum connection.
- Q. Pressure connection for steam.

IV *Molding with Internal Bag Pressures.*
- T. Outside mold, metal or heavy wood frame. If of metal may be steam heated.
- U. Sturdy cap, bolted to T.
- V. Inlet for air, steam or hot water.
- W. Rubber bag, inside of sub assembly.

rubber bag, somewhat like an air mattress, is placed over the freshly spread wood layers, and the outer shell is dropped over the whole and bolted to the base. The rubber bag is then inflated with air, hot water or steam, and the wood layers are pressed and bonded together as well as to the frame members inserted in the mold. This method has been successful in making plywood hulls for small boats, using an inside mold of skeletonized wood, in which ribs are set flush for bonding to plywood.

Another process of molding plywood parts is shown in Fig. 4-III, in which a sub-assembly is enclosed in a rubber bag and the bag placed in a pressure tank. No vacuum is necessary here, merely a *vent to atmosphere*. The tank is usually filled with steam at 50 to 100 lbs. pressure. This method can be applied to such sub-assemblies as wings, ailerons, tail parts, etc., where plywood skin covering can be bonded direct to skeleton frame, spars, ribs, etc., without nailing, except the minimum necessary to hold parts in position until bonded.

The fourth type (bottom sketch Fig. 4-IV) is substantially the reverse of II, with a *rubber bag* placed *inside* rather than outside of the plywood to be bonded. It is useful where several layers of 2-ply are to be glued together after bending, and bonded into a rigid leading edge. This cannot be done in III, because of inadequate pressure where plywood is not supported by frame work. One of the distinct advantages of this outer-form-inner-bag method is the smoothness of the outside surface, reducing air resistance in flight, with all irregularities occurring on the inside, adjacent to the bag.

These several molding methods have distinct possibilities, and there are many other possible combinations. The mechanical adaptations are not difficult, but the chief obstacle to broader use is the lack of standardization in aircraft design. There is no reason why these rubber bag methods should not find extensive use in airplane sub-assemblies, when and if some *standardization* becomes well established. Whether the processes will be adapted to large units like fuselage halves or complete planes is a problem that time and experience will reveal. The excellent weight/strength ratios of plywood and the smooth exteriors, without rivets, both add to the air effectiveness of such types of planes.

The resin adhesives are admirably adapted to these molded plane designs. If sufficient heat and pressure is attainable the phenolic liquid resins are preferable while the urea resins will give good results if conditions are unfavorable for the use of phenolics.

HIGH FREQUENCY ELECTROSTATIC METHODS

The conventional method for manufacturing aircraft plywood with synthetic resin adhesives has been the use of the steam heated platen in a hydraulic press. While entirely satisfactory on thin plywood, a definite limit in thicknesses appeared when time of heat penetration became excessive, and the temperature gradient required to polymerize the resin in the central layers caused an overdrying of the outer layers.

This problem is well on its way toward solution by the utilization of *high frequency electrostatic fields*. The material to be heated is placed between the electrodes, and experience indicates that suitable temperatures for resin cures can be obtained very quickly, even in the center of a block or skeleton construction of substantial thickness. As a matter of fact, the temperatures attained in the wood are less than those that occur in the adhesive material. This process shortens the bonding time to such an extent that the wood layers suffer little loss of moisture content.

If is of course necessary to obtain the required specific pressures by mechanical means that are properly insulated.

This process is admirably adapted to such thick assemblies as the propeller blanks, described later,[25, 41] where heat penetration by the conventional method would be impossible. Whether it will be economic for thin plywood remains to be determined. It is also well suited to cure resin bonds expeditiously in wood and plywood sub-assemblies on jigs or even in various types of rubber bag assembly processes, heretofore described.

Wood and Plywood Constructions

There are fundamental differences in design requirements between wood and metal in aircraft construction. Wood has bulk and stiffness with high strength/weight ratios. Wood surfaces can be glued together. These facts give substance to the belief that molded plywood parts, with light, but strong arch effects, will be important factors in the aircraft of the future. Metal parts may be thinner and smaller for a given strength, but their attachment methods, by welding and riveting, are much more localized than the gluing together of wood parts over substantial areas. Obviously, the mere substitution of plywood for sheet metal, or vice versa, without fundamental design changes, may lead to serious difficulties. Maximum advantages for each material are only obtainable by intelligent utilization of wood experience on its designs and of metal knowledge on metal constructions.

(a) *Laminated Spars.* The term laminated refers to the parallel grains of the adjacent layers, while regular plywood has alternately crossed grains. A solid single piece of wood, of same size and species, is less desirable for aircraft work than a laminated piece of the same dimensions, since the fabrication permits balancing or bracing grain effects, reinforcement of adjacent layers, freedom from checking and more uniform moisture content. While spars for small "cub" planes are often of solid wood, there is a distinct tendency to make them of *laminated layers* of sawn or sliced veneer. In general these spars are approximately 1 in. × 6 in. at the large end, tapered toward the small end, and in solid lumber seldom are available over 20 feet long. If laminated from $^1/_8$ in. spruce, the lengths can be increased to almost any desired point by staggering and scarfing the splices as shown in Fig. 5.[52] With a properly applied resin adhesive the quality of the laminate will be superior to solid spruce and the cost not out of line.

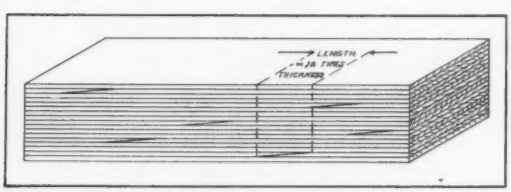


Fig. 5. Laminated spars of Sitka spruce veneers. Note: Individual layers are scarfed (L = 12 T) to utilize shorter sheets of veneer; scarfs are staggered for strength distribution.

In larger types of trainer planes spars may either be made of overlaid $^1/_2$ in. layers of solid wood or by aggregating pieces of laminated constructions as shown in Fig. 5. These large spars are often built up to 3 in. to 4 in. thickness at the fuselage ends, for reinforcing, while the layers taper or leaf-out toward the outer ends. Some spars are made of hollow beam construction toward the outer end, with thin diagonal plywood covering. Urea resin adhesives are suitable for all spar joints, while phenolic resins are preferable in the plywood used for covering.

(b) *Plywood Ribs and Gussets.* There is a wide range of constructions and designs possible here.[9] It should be kept in mind that, under column types of loading, solid wood often has a favorable strength/weight ratio over plywood, while for distributed strength and non-splitting qualities plywood is far superior to solid wood. As in the case of the spar constructions, urea resins are best for assembly joints, while phenolic resins are to be preferred for joints in the plywood. In the case of such small areas as are involved in rib assemblies, sufficient pressure is often attainable by properly designed and located nails, with or without nailing strips, and sometimes by strong spring clamps. The important point is to bring surfaces into intimate contact.

(c) *Skin Coverings of Plywood.* One of the fundamental advantages of plywood is its stiffness/weight factor, which can be simply illustrated as follows: Various types of aluminum sheets have a specific gravity of 2.8 approximately, while spruce plywood has a corresponding characteristic of 0.5 to 0.6. Hence for an equal weight, plywood can be four to five times as thick, or for equal thickness, plywood is correspondingly lighter. Plywood can be glued to the ribs and spars, while metals have to be riveted, a distinct disadvantage. The springiness of plywood renders it less easily damaged, and if damaged it is much simpler to repair.

Certain combinations of plywood thickness and curvature can be bent cold and dry. If the curve is too severe, Tego bonded plywood can be *softened by steaming* and then bent and dried over either a single or double form, which may be heated. Sometimes rather sharp curves are facilitated by bending at 45° with the face of the plywood, rather than parallel or perpendicular to any layer within the plywood. It is becoming increasingly apparent that thicker skin coverings, at such locations as leading edges, may permit the elimination of a substantial number of ribs, with consequent reductions in time, weight and cost. In some cases these thicker plywood surfaces may consist of several layers of 2-ply, bonded together as suggested in Fig. 4-IV, with rubber bag pressure.

(d) *High Density Reinforcing Plates.* Solid lumber, such as the spruce used in spars, splits easily and has very low bolt holding power. Hence spruce spars re-

quire sturdy reinforcement where they are attached to the fuselage or landing gear. While this is often done with metal plates, it is possible to get very excellent results from the use of reinforcing plates of high density plywood of which the strength characteristics are given in Table 2.[47] It is to be noted that the resistance to shear is increased some seven fold, as between solid wood and plywood pressed at 1000 or 1500 lbs. specific pressure. While both solid maple and normal pressed plywood (200 lbs. per sq.in.) are used for such reinforcing, the denser plywood product offers distinct advantages in the weight/shear ratio, *i.e.*, where shear resistance increases some 700 per cent, the specific gravity or weight only increases 114 per cent.

One important factor in using high density plywood for reinforcing plates is to have the surface, adjacent to the soft wood, sufficiently *roughened* so that the bond will be both *mechanical* and *adhesive*. A simple way to accomplish this is to have one surface of the high density plywood pressed (as it is made) against a knurled plate, or even against a properly proportioned metal screen, so that the resulting ridges and valleys are from $1/32$ in. to $1/16$ in. high and not farther than $1/8$ in. apart. Such a roughened surface can be pressed into the spruce by the bolts and will result in a mechanical grip of unusual strength.

While the spar is the most obvious place on which to use high density plywood reinforcing plates, with mechanical interlocking into the wood surfaces, there may be other locations where such strength developments can be utilized to definite advantage.

(e) *Propeller Constructions*. Progress in the propeller field is rapid, and it would be venturesome to predict the extent to which wood and plywood, with its newly developed attributes of high density, may enter the field of propeller design.

At the present time many, if not most, of the double-blade straight propellers for "cub" planes are laminated wood, built up out of $3/4$ in. birch, mahogany or walnut lumber, and this type of construction seems well established.

As the service becomes more exacting on larger planes of the various trainer types, there is a tendency to use two single blades, mounted on a straight line, in metal hubs provided with clamps that permit adjustment of pitch, on the ground, but are in fixed position during flight. Here plywood fits the requirements adequately, and the blanks may be made with high density at the hub end and low at the tip, as is outlined below for larger sizes.

Large single propeller blades have been made of wood, using strips $1/2$ in. thick, and are very dense "Jicwood" or "Pregwood" at the hub end.[41] This dense portion is scarfed to spruce, for lightness, toward the tip end, where gripping power is not essential. These laminae are built up into suitable blanks for blades that may approach 12 in. in width and 10 ft 0 in. in length.

Another type of propeller construction is built up from $1/2$ in. thick laminae made on a *variable density* basis as shown in the upper sketch of Fig. 6. The

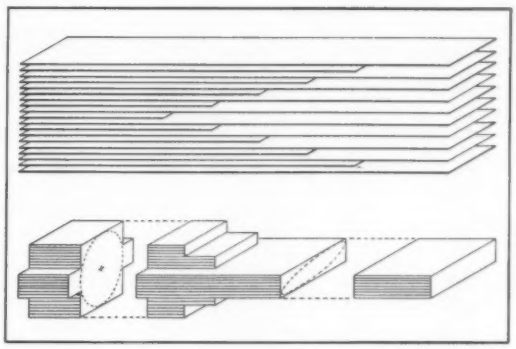


FIG. 6. Laminated propeller blanks with differential density. Upper: Method of assembling $1/2$" layers from thin veneers, using extra layers to give additional density at hub end. Unit is pressed and bonded to uniform thickness. Lower: Combining the above layers into the propeller blank, with adequate thickness for hub anchorage and sufficient width for required blade dimensions.

veneer layers[25, 46] are varied in length to give such density as strength requirements may dictate at any section in the propeller. In general the initial thickness at the hub end will be some 175 per cent of the final thickness and at the tip approximately 115 per cent. The whole is hot pressed, with Tego Film, to a uniform thickness controlled by metal thickness separators in the press. The density requirements may be varied by the species, the bulk and the pressure. In some instances it may be desirable to cross-lay the shorter layers of veneer, but this will depend on design requirements. These $1/2$ in. laminae are then built up into the desired size blank, of which a type is shown in the lower sketch of Fig. 6. The dotted lines indicate approximately the final shape.

Developments in wood propeller design are likely to become increasingly important in the near future.

STATUS OF GOVERNMENT SPECIFICATIONS

The Army and Navy specifications for aircraft plywood have been combined in AN-NN-P-511[56] and stipulate two grades of plywood, *Standard* and *Waterproof*. In the latter, the soaking and fungus tests eliminate all adhesives except the resins.

In the matter of assembly adhesives, the Army and Navy publish separate specifications,[57] which are cited in the Bibliography.

Definite progress toward revision of these specifications is now under way, incorporating the results of recent experience with resins.

PHYSICAL PROPERTIES OF PLYWOOD

Fundamental data on the strength characteristics of

TABLE 4

Plywood Weights

Computed on Haskelite Constructions

Species of {Face and back / Other plies}			Birch / Birch	Birch / Poplar	Mahogany / Poplar	Poplar (3) / Poplar
Thickness						
Nominal	Limits	Number of Plies	Estimated Weights per sq.ft. (1)			
3/64 in.	0.040–0.058 in.	3	0.21	(2) 0.21	0.18	0.17
1/16	0.055–0.075	3	0.30	0.25	0.22	0.20
3/32	0.085–0.105	3	0.40	0.35	0.29	0.27
1/8	0.115–0.135	3	0.52	0.43	0.37	0.35
5/32	0.145–0.170	3	0.60	0.50	0.43	0.40
3/16	0.170–0.200	3	0.71	0.58	0.50	0.47
3/16	0.170–0.200	5	..	0.58	0.53	0.50
7/32	0.205–0.235	5	..	0.74	0.65	0.62
1/4	0.235–0.265	5	..	0.80	0.71	0.68
5/16	0.300–0.325	5	..	0.95	0.84	0.80
3/8	0.360–0.390	5	..	1.05	0.97	0.93
7/16	0.420–0.460	7	..	1.30	1.19	1.15
1/2	0.480–0.520	7	..	1.47	1.36	1.32
9/16	0.545–0.580	7	..	1.62	1.47	1.41
5/8	0.600–0.650	9	..	1.96	1.70	1.59
3/4	0.725–0.775	9	..	2.35	2.01	1.88
1 mm.	0.029–0.049 in.	3	0.17	..	..	..
1 1/2	0.049–0.069	3	0.28	0.24	0.21	0.20
2	0.069–0.089	3	0.37	0.33	0.27	0.25
3	0.108–0.128	3	0.52	0.43	0.37	0.35

Explanatory Notes to Table 4

(1) Nominal weights given in this table are based on the exact veneer thicknesses required, the glue weighing 0.013 lb. per sq.ft. of glue joint, and the weight of the wood in pounds per cubic feet as follows:

Birch	43.2 lbs.	Poplar	28 lbs.
Mahogany	32.2	Spruce	27

The moisture content of the plywood is assumed to be 12%.

(2) The weights for the 3/64 in. thickness are based on birch being used for the core. United States Army and Navy specifications call for all plies of birch in case of any panel under 1/16 in. thickness.

(3) The weights given for poplar plywood are, for all practical purposes, the same as for spruce plywood.

solid wood are well established. It should be noted that the behavior of wood under stress loadings is sometimes quite different from that of metals, since wood is relatively *non-homogeneous*, while most metals are quite *homogeneous*. Most technical information on the strength of materials has been in the metal field and has been based on the behavior of metals. Since wood reacts quite differently from metal in some respects, it is not always possible to consistently compare the performance of wood and metal. And as a consequence some of the desirable qualities of wood have not been adequately recognized.

Plywood, while depending for its strength characteristics on the strength elements of the various sheets of veneer of which it is composed, still presents several new qualities of distinct value. In addition there are many principles of design and types of construction in plywood that, under intelligent application, can be utilized to secure special strength requirements that far exceed the normal in either wood or plywood. It is for this reason that plywood offers unusual advantages to the aircraft engineer. It is obvious that these special plywood advantages can seldom be expressed in standard tables of strength characteristics, but must be evaluated in terms of understanding in the use of plywood, and from experience in its application.

Fundamental data on wood strength is given in "Strength of Aircraft Elements, ANC-5" issued by the Army-Navy-Civil Committee on Aircraft Requirements. The practical usefulness of this data has been enhanced by the engineers of a leading aircraft plywood manufacturer,* who have re-arranged this fundamental data for the types of plywood customarily used in recognized aircraft design. This information is published herein for the first time, with the permission of its sponsors and with an acknowledgment by the author for this distinct contribution to aircraft design data.

Tables 4, 5 and 6 are arranged for the species of wood and thickness of plywood usually employed in aircraft construction, and their derivation from ANC-5 is fully outlined in the accompanying explanatory notes.

Table 7 is an arrangement, by strength increments, of data presented to the American Society of Mechanical Engineers,[47] based on preliminary tests on high density plywood. Further tests along this line are in progress.

Table 8 indicates the relation between this high density plywood and the more dense species of solid wood that are not included in the ANC-5 tabulations.

CONCLUSIONS

It becomes apparent that plywood, with the improved resin adhesives now available, offers to airplane designers and builders a material, the desirable characteristics of which have been seriously under-estimated. The more recent techniques of thinner veneers, multi-

*The Haskelite Mfg. Co., Chicago and Grand Rapids.

TABLE 5

Estimated Tensile Strength and Bearing Strength of Aircraft Plywood
Based and Computed on Haskelite Construction

Species of {Face and back / Other plies}		Birch / Birch		Birch / Poplar		Mahogany (b) / Poplar		Poplar (d) / Poplar	
Nominal Thickness	Number of Plies	Long.	Trans.	Long.	Trans.	Long.	Trans.	Long.	Trans.
		Estimated Tensile Strength—lbs. per inch Width (a)							
3/64 in.	3	600	440	600	260	300	240	340	250
1/16	3	820	730	810	430	430	390	470	420
3/32	3	1210	880	1200	530	620	470	680	520
1/8	3	1270	1420	1260	820	680	760	740	810
5/32	3	1670	1670	1660	970	880	890	970	970
3/16	3	2000	2000	1990	1170	1050	1075	1160	1160
3/16	5	....	....	1660	1170	1085	1100	1140	1160
7/32	5	....	....	2740	1060	1800	970	1910	1050
1/4	5	....	....	2790	1340	1860	1230	1960	1320
5/16	5	....	....	3400	1420	2240	1300	2370	1410
3/8	5	....	....	3150	2340	2220	2230	2320	2320
7/16	7	....	....	3900	2720	2730	2600	2870	2700
1/2	7	....	....	4370	3160	3210	3040	3340	3140
9/16	7	....	....	5120	3250	3510	3090	3740	3230
5/8	9	....	....	5230	3570	4070	3440	4190	3550
3/4	9	....	....	6290	4410	4740	4250	4900	4390
1 mm.	3	470	420	460	250	240	230	250	250
1 1/2	3	810	650	800	390	420	340	460	380
2	3	1190	690	1180	430	600	370	660	420
3	3	1270	1420	1260	820	680	760	740	810
		Estimated Bearing Strength—lbs. per inch Width (c)							
3/64 in.	3	230	154	221	110	202	115	154	106
1/16	3	307	269	298	182	269	192	202	182
3/32	3	451	317	442	221	394	221	307	211
1/8	3	461	528	451	365	403	374	317	355
5/32	3	614	614	595	432	538	432	413	413
3/16	3	739	739	720	518	643	518	499	499
3/16	5	720	739	624	509	576	509	490	499
7/32	5	1306	566	114	394	1037	403	893	374
1/4	5	1325	768	1123	538	1046	538	902	518
5/16	5	1613	787	1373	547	1277	547	1094	518
3/8	5	1478	1478	1219	1018	1142	1018	998	998
7/16	7	....	....	1517	1171	1421	1171	1238	1142
1/2	7	....	....	1728	1363	1632	1363	1450	1334
9/16	7	....	....	2016	1373	1891	1382	1651	1344
5/8	9	....	....	2131	1498	2035	1498	1853	1469
3/4	9	....	....	2515	1872	2390	1882	2150	1843
1 mm.	3	173	154	168	110	149	110	115	106
1 1/2 mm.	3	307	230	298	168	249	168	202	158
2	3	451	240	442	173	394	178	307	163
3	3	461	528	451	365	403	374	317	355

These strength values apply only to aircraft plywood, made under Type II of the U.S. Army and Navy Specifications.

Explanatory Notes to Table 5

(a) In ANC-5, "Strength of Aircraft Elements," Table 2-2, on pages 2–8, reports tests made upon *tensile strength* of plywood panels of 35 species of wood. Each panel had three plies of the same thickness and of the same species. Strength of two kinds are reported, (1) for tension parallel to the face grain and (2) for tension perpendicular to the face grain. The results are expressed in pounds per square inch of the complete section, and they may be called T_1 and T_2, respectively.

Let us use T_L and T_T to represent the tensile strength of the veneer, T_L along the grain and T_T across the grain. Then we should have

$$T_L = 2T_1 - T_2 \text{ and } T_T = 2T_2 - T_1$$

The tensile strength used as a basis for the above tabulation has been obtained in this manner from the values given in ANC-5, and are:

Birch..... T_L = 18,700; T_T = 2,200
Spruce..... T_L = 7,950; T_T = 900
Mahogany..... T_L = 9,000; T_T = 1,170
Poplar..... T_L = 10,060; T_T = 2,050

all in pounds per square inch.

(b) The estimated *tensile strengths* given for Mahogany plywood are, for all practical purposes, the same as for Spruce plywood.

(c) The *bearing strength* values tabulated above are based upon the following values assumed for Haskelite plywood in pounds per square inch:

	Birch	*Mahogany*	*Poplar*	*Spruce*
Bearing strength along grain of veneer	7300	6500	5000	5000
Bearing strength across grain of veneer	400	440	200	220

The above unit bearing values, along the grain, reproduce values given in column 12 of table 2-1, pages 2–8 of ANC-5, "Strength of Aircraft Elements." To obtain the above unit bearing values across the grain, the values given in column 13, of the above reference, have been divided by four, because of such different strains involved in bringing wood up to maximum bearing, depending upon the direction of the grain.

(d) The estimated *bearing strengths* given for Poplar plywood, are for all practical purposes, the same as for Spruce plywood. Compare the bearing strengths of the two woods as shown in the above footnote.

TABLE 6

Plywood Bending Characteristics
Computed on Haskelite Construction

(See Explanatory Notes on Following Page)

Nominal Thickness	Number of Plies	Stiffness EI Long.	Stiffness EI Tran.	Basic Moment 1000 lbs. per sq.in. Long.	Basic Moment 1000 lbs. per sq.in. Tran.	Elastic Radii Long.	Elastic Radii Tran.
				All Plies Birch			
3/64 in.	3	16.9	2.0	0.35	0.10	5.1 in.	2.0 in.
1/16	3	42.9	6.7	0.59	0.20	7.6	3.5
3/32	3	134	15.9	1.37	0.42	10.4	4.1
1/8	3	282	65	2.22	0.95	13.3	7.1
5/32	3	560	107	3.57	1.36	16.5	8.3
3/16	3	970	186	5.16	1.98	19.8	9.9
1 mm.	3	9.7	1.6	0.23	0.08	4.4	2.1
1 1/2	3	36.8	4.9	0.54	0.17	7.2	3.1
2	3	88	7.7	1.00	0.26	9.28	3.1
3	3	257	52	2.28	0.80	13.3	6.8
				Faces Birch—Other Plies Poplar			
3/64 in.	3	16.8	1.7	0.34	0.12	5.1	2.4
1/16	3	42.9	5.5	0.59	0.22	7.6	4.1
3/32	3	134	13.4	1.37	0.47	10.4	4.7
1/8	3	280	50.9	2.22	1.03	13.3	8.3
5/32	3	560	86	3.6	1.5	16.5	9.5
3/16	3	969	148	5.1	2.17	19.8	11.4
3/16	5	800	288	4.3	3.1	23.0	19.6
7/32	5	1,540	336	6.5	3.2	25.2	17.7
1/4	5	2,100	600	7.9	4.8	28.0	20.9
5/16	5	3,960	940	12.9	6.8	32.0	22.8
3/8	5	5,300	2,870	14.1	13.9	39.6	34.4
7/16	7	9,300	4,580	20.7	16.8	47	40
1/2	7	13,600	6,490	26.2	21.7	55	49
9/16	7	20,700	7,400	37.0	25.0	60	50
5/8	9	25,000	11,400	40	31.0	67	62
3/4	9	44,100	20,100	59	46.0	79	72
1 mm.	3	9.7	1.3	0.23	0.09	4.3	2.4
1 1/2	3	36.8	4.1	0.53	0.19	7.2	3.6
2	3	87.9	6.8	1.00	0.32	9.3	3.6
3	3	256	41.3	2.22	0.87	13.3	7.8
				Faces Mahogany—Other Plies Poplar			
3/64 in.	3	11.9	1.4	0.34	0.10	4.0	2.4
1/16	3	30.5	4.9	0.59	0.20	5.9	4.1
3/32	3	95	11.4	1.37	0.40	7.9	4.7
1/8	3	200	46.8	2.22	0.94	10.2	8.3
5/32	3	398	77.8	3.6	1.36	12.6	9.5
3/16	3	690	135	5.2	1.97	15.2	11.4
3/16	5	586	278	4.4	3.0	15.1	15.6
7/32	5	1,110	316	6.6	3.0	19.3	17.7
1/4	5	1,510	576	8.0	4.5	21.5	20.9
5/16	5	2,850	980	13.1	6.4	24.7	22.8
3/8	5	3,840	2,790	14.4	13.6	30.3	34.4
7/16	7	6,910	3,970	21.5	16.3	36.4	40.5
1/2	7	9,600	6,310	27.4	21.3	42.2	49.5
9/16	7	15,300	7,100	38.0	24.0	45.5	49.6
5/8	9	19,500	11,100	44	30.0	50.6	52.4
3/4	9	33,600	19,500	58	45.0	60.7	72.5
1 mm.	3	6.9	1.2	0.23	0.08	3.4	2.4
1 1/2	3	26.1	3.6	0.54	0.17	5.5	3.6
2	3	62.5	5.6	1.00	0.26	7.1	3.6
3	3	182	37.4	2.38	0.80	10.6	7.8
				All Plies Poplar			
3/64 in.	3	12.3	1.4	0.34	0.10	6.0	2.4
1/16	3	31.4	4.9	0.59	0.20	8.9	4.1
3/32	3	98	11.6	1.38	0.40	11.9	4.8
1/8	3	204	47.1	2.22	0.95	15.4	8.3
5/32	3	409	78	3.6	1.36	19.0	9.5
3/16	3	710	136	5.2	1.98	22.8	11.4
3/16	5	600	278.4	4.4	3.0	22.7	15.6
7/32	5	1,140	316.8	6.5	3.0	33.0	17.7
1/4	5	1,560	576	8.0	4.6	32.4	20.9
5/16	5	2,930	880	13.1	6.4	37.1	22.8
3/8	5	3,950	2,800	14.4	13.6	45.8	34.1
7/16	7	7,000	3,980	21.4	16.3	54.8	40.5
1/2	7	9,980	6,300	26.9	21.3	63.8	49.5
9/16	7	15,600	7,100	38.0	24.0	68.6	49.6
5/8	9	19,900	11,100	44	30.0	76.3	62
3/4	9	34,500	19,600	63	45.0	43.5	72
1 mm.	3	7.1	1.2	0.23	0.08	5.1	2.4
1 1/2	3	26.8	3.6	0.54	0.17	8.4	3.6
2	3	64.2	5.7	1.00	0.27	10.7	3.6
3	3	188.0	37.6	2.40	0.80	15.4	7.9

These strength values apply only to aircraft plywood made under Type II of the U.S. Army and Navy Specifications.

Explanatory Notes to Table 6

Each characteristic applies to a strip of the panel *one inch in width* in which the face grain is either longitudinal (Long.) or transverse (Tran.). The strip is bent in a plane perpendicular to the face.

Stiffness (EI) is expressed in (in.)² lb. The *basic moment* gives a stress of 1000 lb./sq.in. in the outermost fibre whose direction is parallel to the length of the strip. It serves the purpose of section modulus. It is expressed in inch-pounds. When the strip is bent to the *elastic radius*—expressed in inches—the maximum fiber stress reaches the assumed elastic limit in bending. For permanent bending, plywood should be moistened or steamed.

The tabulated values are based upon the following properties of the species of wood, all in lb./sq.in.: *Modulus of Elasticity* along the grain—1,960,000 for Birch; 1,390,000 for Mahogany; 1,430,000 for Poplar and 1,430,000 for Spruce. *Elastic Limit* in bending—9500 for Birch; 8800 for Mahogany; 6000 for Poplar and 6200 for Spruce.

These are found in ANC-5, "Strength of Aircraft Elements," Table 2-1, on pages 2–8, but the values of E have been increased 10% in accordance with note No. 2 of this table. The modulus of elasticity across the grain is taken as 5% of the value along the grain.

In making the panels, the veneers are compressed. It has been assumed that the thickness of each panel is precisely the nominal value, and that all its veneers are compressed by the same per cent. To obtain the tabular values, the moduli of elasticity have been increased in proportion to this compression.

The tabulated values shown for Poplar plywood are, for all practical purposes, the same as for Spruce plywood; however, it must be remembered that Spruce surpasses Poplar in absorption of work in bending. See column 10 of Table 2-1, on pages 2–8 of ANC-5.

TABLE 7

Predetermination of Strength Values of High Density Birch Plywood

Type of Stress	Veneer Thickness, Inch	Cross Layers Veneer	Tego Film Layers	Specific Gravity	Specific Pressure lb. per sq.in.	Strength Values lb. per sq.in.	Notes
Compressive	1/8	Alternate	Single	0.77	500	7,890	
	1/16	Alternate	Single	0.72	500	7,980	
	1/48	Alternate	Single	0.77	200	8,580	
	1/48	Alternate	Single	1.05	500	11,720	2
	1/48	Every 5th	Single	0.73	500	12,130	3
	1/48	Every 10th	Single	0.77	500	13,040	3
	1/48	Alternate	Double	1.10	500	13,300	
	1/48	Alternate	Single	1.30	1000	14,220	
	1/48	Alternate	Single	1.35	1500	14,540	1
Tensile	1/8	Alternate	Single	0.77	500	11,840	
	1/48	Alternate	Single	0.77	200	12,550	
	1/16	Alternate	Single	0.72	500	13,920	
	1/48	Alternate	Single	1.05	500	19,160	2
	1/48	Every 5th	Single	0.73	500	19,370	3
	1/48	Alternate	Double	1.10	500	19,800	
	1/48	Every 10th	Single	0.77	500	19,920	3
	1/48	Alternate	Single	1.30	1000	25,740	
	1/48	Alternate	Single	1.35	1500	28,490	1
Shear	1/8	Alternate	Single	0.77	500	6,060	
	1/16	Alternate	Single	0.72	500	6,330	
	1/45	Alternate	Single	0.77	200	7,240	
	1/48	Every 10th	Single	0.77	500	8,370	3
	1/48	Every 5th	Single	0.73	500	8,480	3
	1/48	Alternate	Single	1.05	500	11,540	2
	1/48	Alternate	Double	1.10	500	14,520	
	1/48	Alternate	Single	1.30	1000	16,180	
	1/48	Alternate	Single	1.35	1500	16,360	1

NOTES: 1. Increase of pressure, 1000 to 1500 lbs. per sq.in., gives little added strength.
2. Basic standard of this series of tests.
3. Difference between crossing every fifth and tenth layer is not significant.

TABLE 8

Extra-Dense Normal Solid Woods and Approximate Equivalents in High Density Plywood

Species	Specific Gravity (a) Range	Specific Gravity (a) Average
Apple	0.66–0.84	0.75
Beech	0.70–0.90	0.80
Boxwood	0.95–1.16	1.05
Dogwood	0.68–0.77	0.72
Ebony	1.11–1.33	1.22
Hickory	0.62–0.78	0.70
Hornbeam	...	0.75
Lancewood	0.68–1.00	0.84
Lignum Vitae	1.17–1.33	1.25
White Oak	0.69–0.86	0.77
Satinwood	...	0.95
Teak	0.66–0.98	0.82

Plywood Construction (b)	Film Layers	Specific Pressure lbs. per sq.in.	Specific Gravity
17/16 in. Birch	Single	500	0.72
45/49 in. Gum, red	Single	500	0.73
57/48 Birch	Single	200	0.77
77/45 Poplar	Single	500	0.82
89/48 Birch	Single	500	1.05
73/48 Birch	Double	500	1.105
81/48 Birch	Single	1000	1.30
105/45 Poplar	Single	1500	1.32
85/48 Birch	Single	1500	1.36

(a) Specific gravity from Kent's Handbook, 1938 edition.
(b) All constructions are standard alternate crossings.

plies, various arrangements of cross layers, high pressures and degrees of resin impregnation, afford opportunities for special strength combinations that will successfully solve many problems in the aircraft design of the future.

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* Many of these items are not referred to in the text; they are listed here as additional references.

Institute Notes

Membership Roster to be Published with the April Issue

The 1941 issue of the Membership Roster of the Institute is now on the presses and will be sent to all members and subscribers with the April issue of the Journal. The Roster will be similar in form and content to the previous issue and will contain the names and products of Corporate Members, alphabetical list of individual members and list by grades giving brief biographical data for each member. Membership of Student Branches and other information about the Institute will be published. The Roster has become well established as a "Who's Who in the Aeronautical Sciences" and is used throughout the year as a biographical reference book in the aviation industry.

New Corporate Members

Four companies engaged in aeronautical work have been added to the list of Corporate Members of the Institute for 1941. They are The American Rolling Mill Company, Middletown, Ohio, manufacturers of rolled steel and stainless steel; Engineering and Research Corporation, Riverdale, Maryland, builders of the "Ercoupe" aircraft, propellers and aircraft and propeller production machinery; Fleetwings, Inc., Bristol, Pennsylvania, constructors of the civil and military aircraft bearing the company name and also of construction materials, floats and skis, hydraulic systems, instruments and other accessories; Northrop Aircraft, Inc., Hawthorne, California, manufacturers of military aircraft. The membership of the Institute appreciates the contributions of these companies to the publication of the Journal and other activities of the Institute. A number of other companies are planning to take out Corporate Membership very shortly. Their affiliation will be announced as soon as it has taken effect.

Changes of Address

Members and subscribers are urged to notify the Institute immediately of any proposed change of address. Copies of the Journal sent to old addresses are returned directly to the Institute and not forwarded because of postal laws and regulations. The over-print of the Journal is limited, therefore copies are not sent to new addresses until the first copy has been returned to us by the Post Office. The cooperation of members and subscribers in this matter will be greatly appreciated.

Student branches

Agricultural and Mechanical College of Texas. At the first meeting of this newly formed Branch, on November 19th, Prof. Howard W. Barlow explained to the one hundred and twenty students present the aims and activities of the Institute. Officers were elected as follows: Howard W. Barlow, Honorary Chairman; W. W. Sullivan, Chairman; B. S. Hutchins, Vice-Chairman; and D. M. Earley, Secretary. At subsequent meetings, the Institute films "Conquest of the Air" and "Streamline Visualization" were shown.

University of Detroit. The Continental Trophy, awarded by Continental Motors, Inc., for the best design submitted by a Junior Aeronautical Engineering student of 1940, was presented to Fred V. Gieryn. The presentation was made by Prof. George J. Higgins at a meeting held on January 25th which was attended by about forty students. Following this, R. N. Dubois, in charge of Engine Production of the Packard Motor Car Company, gave an illustrated talk on the test facilities of that company for liquid-cooled engines.

Iowa State College. R. E. Hinkle, of Transcontinental & Western Air, spoke at a meeting held on December 14th. Following this, a C.A.A. movie was shown. Prof. L. M. Headley of the Mechanical Engineering Department gave a talk on the mathematical analysis of vibration characteristics at a meeting held on January 23rd.

Louisiana State University. Officers for the second semester of the 1940–41 session are: William G. Brown, Honorary Chairman; A. C. Sheffield, Chairman; and J. A. Falvey, Secretary-Treasurer.

University of Minnesota. A talk on "Aircraft Maintenance" was given by Lt. Lindner, U.S.M.C., at a meeting held on January 21st.

University of Notre Dame. At meetings held on October 17th, November 21st, January 15th, and on February 19th, talks were given by Prof. M. J. Thompson, University of Michigan, Ralph S. Damon, American Airlines, Lt. A. N. Kelly, United States Navy, and H. G. Tarter, Bendix Aviation Corporation.

Rensselaer Polytechnic Institute. Officers for the current year were elected as follows: Prof. A. J. Fairbanks, Honorary Chairman; David A. Anderton, Chairman; Theodore T. Brundage, Treasurer; and Ralph P. Bielat, Secretary. The Institute film on "Streamline Visualization" was shown at a meeting held on February 6th and an explanation given by Dr. P. E. Hemke.

Personnel Opportunities

The Personnel Bureau serves individual members, as well as organizations seeking to employ aeronautical specialists. Any member or organization may have requirements listed without charge.

Wanted

Small, progressive and well established company with strictly modern plant requires a Chief Engineer with at least 12 years' experience in the design and construction of military or commercial aircraft. Applicant must have a background of education and performance indicating that he is thoroughly familiar with latest design and construction practices, capable of directing men and has developed new and successful designs and carried same through production. Excellent opportunity for man with proper qualifications. Address reply to Box 127, Institute of the Aeronautical Sciences.

Established manufacturer of patented aircraft components and accessories, located in the New York area, whose products are in continually expanding use, requires the following specialized personnel. *Design Engineer on Aircraft Mechanical Equipment:* Should have at least ten years' experience and a specialized background in the design of mechanical equipment for aircraft. Experience in machine tool operation, and tooling methods, as a practical adjunct to design experience considered particularly desirable; *Assistant Aircraft Hydraulic Engineer:* Must have a background of at least several years of specialized design experience on aircraft hydraulic equipment. Should be interested in high pressure systems. Work initially to be under general direction of a senior hydraulics engineer of exceptional experience and

reputation. An unusual opportunity for the right man; *Hydraulic Equipment Draftsman:* Should have thorough working knowledge of aircraft drafting standards and hydraulic design specifications and be capable of handling all phases of hydraulic system drafting detail; *Sales Engineer:* Should have aeronautical engineering experience, preferably of project or group leader scope. Should be capable of working intelligently with design staffs of aircraft companies on installation design details of patented accessory equipment. Aggressiveness and sales instinct necessary, with previous sales engineering experience desirable; *Production Engineer:* Should have at least 15 years' first-hand experience in high precision machine work preferably of aircraft or aircraft engine nature. Should have expert knowledge of latest machine tool methods and be capable of production planning and follow-up in connection with the manufacture of high precision aircraft accessory equipment. Comprehensive letters are invited. Data supplied should include age, education, domestic status, aircraft experience, general industrial and commercial experience, references and salary desired and when available. Snapshot is desirable. Address reply to Box 128, Institute of the Aeronautical Sciences.

Available

Ground instructor desires position with aviation school anywhere in United States. Has instructor's licenses, engines, navigation including radio, and meteorology. Can teach any courses including sheet metal and is able to compose curriculum, etc. Address reply to Box 129, Institute of the Aeronautical Sciences.

Changes in Membership

The following changes in the membership of the Institute have occurred since the publication of the previous issue of the Journal.

Elected to Member Grade

Finlay, Donald William, B.S.; M.I.Ae.S.; Structural Engineer, Boeing Aircraft Co.

Herman, Fred Weld, B.S.; M.I.Ae.S.; Chief Engineer, Douglas Aircraft Co.

Jackson, Dugald Caleb, Jr., S.M.; M.I.Ae.S.; Dean of Engineering, Univ. of Notre Dame. (See W.W. in A.; A.M. of S.)

Liljencrantz, Eric, M.D.; M.I.Ae.S.; Asst. Prof. of Medicine, Stanford Univ.; Flight Surgeon, Pan American Airways.

May, Richard Bascom, B.S. in E.E.; M.I.Ae.S.

Melrose, Robert George, Ae.E.; M.I.Ae.S.; Asst. Power Plant Engineer, Republic Aviation Corp.

Salter, Tom, B.S. in Ae.E.; M.I.Ae.S.; Chief Engineer, Cessna Aircraft Co.

Wilkinson, Paul Howard, M.I.Ae.S.; Consultant, Aviation and Diesel Aircraft Engines.

Elected to Industrial Member Grade

Henry-Felleman, Paul, M.I.Ae.S.; West Coast Rep., C. P. Clare & Co.; Aircraft Rep., Leach Relay Co.

Marschner, Donald C., A.B.; M.I.Ae.S.; Office Mgr., Advertising Dept., Shell Oil Co.

Rockefeller, Laurance Spelman, B.A.; M.I.Ae.S.; Mem. Board Directors, Eastern Air Lines; Platt-LePage Aircraft Co.; McDonnel Aircraft Corp.

Westcott, Brayton William, B.S.; M.I.Ae.S.; Sales Mgr., Holley Carburetor Co. (See W.W. in Eng.)

Elected to Technical Member Grade

Ayers, Wilbur Walter, B.S. in Eng.; Design Engineer, Vega Airplane Co.

Balloussier, Oswaldo O., Ae.E.; Head of Engineering Dept., Brazilian Air Corps. Brazil.

Brown, Charles Durward, M.S. in Applied Mech.; Asst. Prof., Univ. of Maine.

Friedman, William Stefan, B.S.; News Editor, "Aeronautical Review," Institute of the Aeronautical Sciences.

Koo, Teh-chang, M.E.; Apprentice, Beech Aircraft Corp.

May, Thomas John, B.S. in M.E.; Stress Engineer, Vultee Aircraft, Inc.

Nowlan, Frederick Stanley, Jr., B.S. in Ae.E.; Instructor, Air Navigation School, R.C.A.F. Canada.

Pagon, Garrett Dunn, A.B.; Stress Analyst, Edward G. Budd Mfg. Co.

Price, Robert Allen, Layout Draftsman, Platt-LePage Aircraft Co.

Ruszaj, Norbert Francis, M.S. in Ae.E.; Instructor in Aero Eng., Univ. of Minnesota.

Necrology

Edgar Thomas Bomer

Edgar Thomas Bomer, a Technical Member of the Institute, died in Burbank, California, on December 1, 1940. Mr. Bomer was born in Brooklyn, N. Y., on December 19, 1913. He attended Rensselaer Polytechnic Institute, graduating in 1936 with a degree of M.E. At the time of his death, Mr. Bomer was employed by the Lockheed Aircraft Corporation.

Fredric Erastus Humphreys

Brigadier General Fredric Erastus Humphreys (U.S. Army, Ret.), a MEMBER of the Institute, died at Miami, Florida, on January 20, 1941.

General Humphreys was the first American officer to make a solo flight in an Army airplane. This flight was made at College Park, Md., on October 26, 1909, under the instruction of Wilbur Wright and preceded by a few minutes the first solo flight of Colonel F. P. Lahm, who was thus the second officer to fly the U.S. Army's Airplane No. 1.

General Humphreys was born in Summit, N. J., on September 16, 1883. He received his commission as 2nd Lieutenant in the Army Corps of Engineers after graduation from the U.S. Military Academy in 1906. He was assigned to aeronautical work under the Chief Signal Officer from June to October, 1909. In 1910 he resigned from the Army to manage The Humphreys Homeopathic Medicine Co., a business founded by his grandfather. He was president of this firm from 1928 until a few weeks before his death.

In 1915 he joined the New York National Guard as a Lieutenant in the 22nd Engineers, served as a Captain with his regiment under Major General John F. O'Ryan at the Mexican border in 1916, and was inducted into Federal Service in 1917 as a Major when his organization became the 102nd Engineers stationed at New York City and later at Ft. Wadsworth, S. C.

He was transferred to the Aviation School at Rockwell Field, Calif., in 1918, and later in the year to the School of Military Aeronautics at Massachusetts Institute of Technology. Upon graduation from the first class in 1919 he was assigned to the Technical Section at McCook Field until his honorable discharge from active service in that year.

A year later he was appointed Lieut. Colonel of his old New York National Guard regiment, the 102nd Engineers. When he retired because of poor health on July 11, 1939, he was a Brigadier General and commanding officer of the regiment.